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Exhibit B

Final Report

June 1975

Payload/Orbiter Contamination Control Requirement Study

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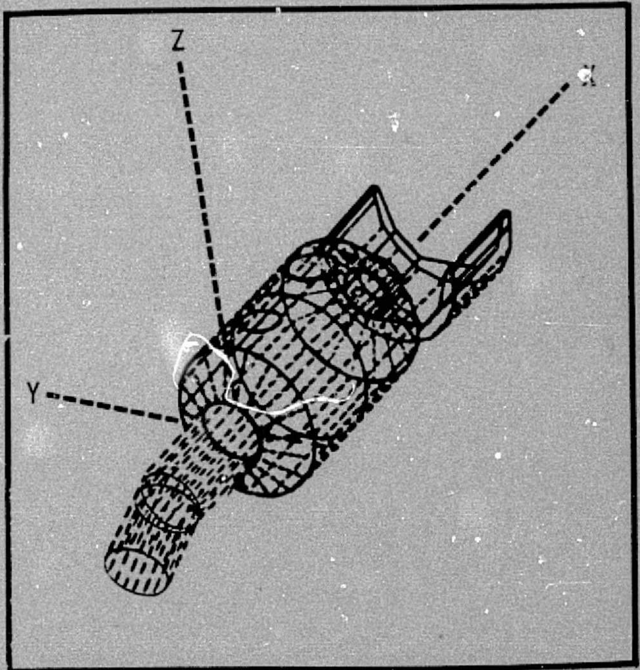

MARTIN MARIETTA

MCR-75-202
June 30, 1975

Technical Report

PAYLOAD/ORBITER CONTAMINATION CONTROL REQUIREMENT STUDY

Final Report

Contract NAS8-30755
Exhibit B

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FOREWORD

This report presents the results of a six month contamination impact analysis upon the Spacelab carrier and the Spacelab carrier upon some of its potential payloads. These results are based upon contamination computer modeling techniques developed to predict the induced environment for Spacelab and to provide the basis for evaluation of the predicted environment against the current on orbit contamination control criteria as specified for payloads (paragraph 1.10.4, ECR #EL52-0032, "Contamination Control Requirements").

Those Spacelab carrier contamination sources evaluated against the stated contamination control criteria were outgassing/offgassing of the major nonmetallic thermal control coating (assumed to be S13G) of the Spacelab carriers, Spacelab core and experiment module and tunnel cabin atmosphere leakage, Avionics Bay Vent, Spacelab Condensate Vent, random particulate sloughing, and the return flux of the molecular content of these sources from the gas-gas interactions with the ambient orbital environment.

These studies indicate that, with the exception of the experiment specified criteria for limiting deposition, the Spacelab carrier can meet the intent of the remaining contamination control criteria through incorporating known contamination control practices. These practices are: incorporating the proper design control, mission timelining and operational constraints as the Spacelab missions become better defined, nonmetallic materials selection expected from ESRO, and proper ground handling procedures to preclude carrying contamination on orbit.

This study has indicated that the one criteria that can not be met is the one specified for deposition which states "no more than 1% absorption from IR through UV by condensibles on optical surfaces". The primary Spacelab carrier contamination source which exceeds this criteria is the deposition from outgassing from the nonmetallic materials. An interpreted outgassing rate associated with the MSFC Skylab ATM testing specification 50M20442 or the current JSC SP-R-0022A specification is on the order of 6×10^{-9} g/cm^2/second at 100°C. The predicted outgassing rate for the Spacelab carrier thermal control coating (assuming 100% coverage) would have to be on the order of less than 10^{-13} g/cm^2/second at 100°C by virtue of area and location to meet the 1% absorption criteria in the ultraviolet spectral range at 1500Å. The study has indicated that to control the Spacelab carrier thermal control material to reduce deposition from outgassing by 3 to 4 orders of magnitude, materials screening requirements more stringent than 50M02442 or SP-R-0022A would have to be

placed upon any Spacelab thermal control material and could present a significant program impact.

To meet the intent of the 1% absorption due to condensibles on optical surfaces criteria, one or possibly a combination of several of the following approaches should be considered:

1) eliminate the use of nonmetallic thermal control material on Spacelab;
2) select nonmetallic materials for Spacelab demonstrating an effective outgassing rate of less than 10^{-13} g/cm^2/second at 100°C;
3) establish protective devices for sensitive instruments such as covers, sensitive surface heaters, and designs with small geometric acceptance angles along with establishing tight operational constraints; and
4) reevaluate the need for a criteria as restrictive as the stated 1%.

The implementation of the above approaches should also take into consideration the ability of the Shuttle Orbiter to effectively satisfy the contamination control requirements in ECR #EL52-0032.

White passive thermal control surfaces on the Spacelab carrier and payloads are predicted to degrade from deposition and ultraviolet photopolymerization of the deposits resulting in an increased solar absorptivity and change in color from a white to a yellow brown. In the case of the Spacelab carrier, with continual reuse, these effects will increase. This increase in solar absortivity will be of varying concerns depending upon the margin of thermal design or tolerances of the affected payload or carrier hardware. This type of discoloration as appeared on Skylab may simply be objectional on the grounds of appearance. Therefore, surface discoloration may dictate significant refurbishment efforts during turnaround activities.

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1. SCOPE

1.1 Purpose - The purpose of this study is to assess the Spacelab's ability as a Payload carrier to meet the on orbit contamination control criteria and to establish for selected missions the impact of Spacelab and Shuttle Orbiter contamination sources upon Spacelab and its Payloads. This study identifies the combined induced environment, the potential susceptibilities of typical Spacelab Payloads and the risk of Spacelab/Payload critical surface(s) degradation, and provides preliminary contamination recommendations for improvements.

Inherent to this study is the utilization of contamination control requirements as they apply to both the flight and ground operations and the analytical approach established to identify the combined contaminant induced environment. It is from both of these factors that the potential susceptibilities of typical Spacelab Payloads, the risk of surface(s) degradation, and the preliminary contamination recommendations for improvements are made.

The contamination control requirements are derived from a number of sources of information. Principally, they result from criteria being developed by Dr. R. J. Naumann, Chairman, Contamination Requirements Definition Group (CRDG), NASA/MSFC. Other sources of information for contamination control requirements are officially identified in References 1, 2, and 3. These criteria/control requirements provide the basis for evaluations presented in this report and are fundamental in the preliminary contamination recommendations identified for contamination improvements.

The analytical approach utilized in this study is that of a contamination computer model which was shown on Skylab to be an effective tool in contamination evaluation and assessment. The effectiveness of this model is dependent upon the quality of input data such as material characteristics, mission profiles, surface temperatures, Payload/instrument configurations, vent characteristics, and the physics involved in establishing how the induced molecular and particulate environment are defined and will interact with critical surface(s) or lines-of-sight in

question. A contamination computer model assessment of this nature allows basic parameters to be identified, geometric considerations to be established, and formulates in a timely and systematic perspective, the trends that evolve from variations of important physical parameters.

This latter point is important in that although the results of this study are consistent with current Shuttle and Spacelab Program development, there are a number of variables associated with the primary data used for evaluation that will continue to change and will require continual update through assessment and evaluation. Those variables which will require varying degrees of continued evaluation and assessment for contamination impact are:

a) changes in the contaminant source characteristics;

b) identification of new contamination sources;

c) changes in operational procedures;

d) changes in experiment/instrument/Payload mixes for missions;

e) changes in requirements to meet experiment/instrument/Payload development;

f) changes in mission profiles (e.g. altitudes, orbital inclinations, beta angles, mission durations, mission timelines, etc.);

g) changes in current contamination control criteria;

h) improvements in contamination methodology development (e.g. second surface source characteristics, return flux from contaminant self scattering, etc.);

i) budgeting of contamination allowances as established by current contamination control criteria (e.g. for a given criteria, the allowance provided to the Shutttle Orbiter, Spacelab, experiment/instrument/Payload, booster system, etc.);

j) operational life times and refurbishment requirements upon relaunch cleanliness levels for subsequent missions; and

k) program impact and resolution will require continuing effort to cover program action items and selected study activities.

1.2 Scope - This report presents the results achieved during a 6 months study effort. The results summarize the 1) continuing contamination math modeling of Spacelab, 2) the results of performing mission compatibility/trade studies using the modeling efforts, and 3) the Spacelab Program related conclusions and recommendations that have evolved. With respect to the continuing Spacelab contamination modeling activity, only significant changes or variations from previous activities are presented. Additional detailed information can be obtained from References 4, 5, and 6 which are previous studies of Spacelab and Shuttle Orbiter contamination control.

1.3 Summary - The following summary is presented to highlight the study efforts conducted under this contract. Specifics of the presented summary can be found in subsequent sections of the report.

1.3.1 Modeling Summary - Three activities were conducted in continuing the development and updating of the Spacelab Configuration Contamination Model (SCCM). These were updates in the modeled geometric configurations, updates in some of the modeled contamination sources, and the establishment of the Mission Profile Data Bank (MPDB). Additional detailed configuration modeling and contamination source information can be obtained from References 4, 5, and 6.

1.3.1.1 Configuration Updates - As reported in Reference 5, nine basic lines-of-sight were established for two of the three modeled Spacelab configurations (i.e. long module/one segment pallet (LMOP) and the five segment pallet (FP) only). These two configurations were initially treated in detail since they geometrically represented the most significant geometric difference in the Spacelab configurations. Only one line-of-sight was established for comparison purposes for the remaining Spacelab

configuration previously considered (i.e. short module/three pallet (SMTP)). During this study, the remaining eight lines-of-sight were established for the SMTP configuration. This latter configuration is representative of the Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) configuration and required updating to meet the Mission 19a (AMPS) mission compatibility analysis.

The thermal profile for the LMOP Spacelab configuration was updated to reflect current thermal analysis being conducted by MSFC. The new thermal data for this configuration has replaced the previous modified thermal profiles developed from Skylab data. The new thermal profile is based upon maximum and minimum temperature ranges and the resulting predictions as developed from this data for the LMOP will reflect this philosophy. This represents a change from previous approaches where beta angle considerations were used to imply the same relative maximum and minimum temperature conditions.

In modifying the thermal profile for the Spacelab LMOP, a number of geometric considerations required modification. The surface segments (nodes) for the contamination configuration of the LMOP were changed from 22 to 47 nodes to reflect similar node structures from the thermal profile analysis. Subsequent changes or updates in configuration thermal profiles should represent minimum future modification as long as similar node structure is maintained. As a result of changing the node structure for the Spacelab LMOP configuration, new view factor runs were developed to establish changes to the mass column densities and the surface-to-surface relationships. These were required since all of these factors (e.g. thermal profile, node structure, and view factors) directly influence mass and number column density calculations and subsequently return flux calculations. For the Spacelab LMOP configuration, these changes resulted in a net decrease by a factor of 2 of previously reported mass column densities. For anticipated similar thermal profile changes in the remaining configurations (as the data becomes available), a net decrease in mass column density by approximately a factor of 2 is anticipated.

As a result of concurrent activities being conducted with the Johnson Space Center for the Shuttle Orbiter, configuration changes in the Shuttle Orbiter have been made which directly and indirectly influence Spacelab mission compatibility analysis activities. These changes are identified herein for completeness and details are presented in Reference 6. The major Shuttle Orbiter configuration changes which have been reflected in this study are:

a) geometric refinement of the Shuttle Orbiter tail (view factors to the payload bay);

b) geometric refinement of the OMS pod structure;

c) payload bay door configuration when opened;

d) increased flash evaporator flowrates (from 5.5 lbs/hour to 15 lbs/hour per nozzle); and

e) detailed geometry modeling of the 900 lb RCS and establishing view factors, mass column density, and return flux levels.

1.3.1.2 Sources Updates - As a part of this study, previous Spacelab sources were reevaluated and some new sources were evaluated for their contaminant potential. The most significant Spacelab source reevaluated during this study was the thermal control coating for the three modeled Spacelab configurations. Currently a S13G type white thermal control paint is being used for this analysis as the anticipated Spacelab thermal control coating. The material characteristics (weight loss as a function of temperature and preconditioning of the coated surfaces) has yet to be specifically established. Previous Spacelab configuration analyses for both offgassing and outgassing of S13G were based on data obtained during the Skylab Program. This assumed a steady state outgassing rate for S13G of 1×10^{-8} g/cm^2/second at 100°C. However, recent data supplied by MSFC has indicated that the steady state outgassing rate could be on the order of 1×10^{-12} g/cm^2/second.

Because of the total area of coverage with thermal control material for the Spacelab configurations, the relative location to sensitive instruments and the wide variations in available S13G test data, any selected thermal control material should be evaluated thoroughly before qualification. This evaluation should provide data compatible to the ability to analyze its contribution to the induced environment. The following recommendations are presented to indicate those considerations felt important in establishing the qualification of Spacelab thermal control material, and, all other major Spacelab nonmetallic materials deemed to present a potential contamination risk:

a) All outgassing data should be supplied in the form of mass loss per unit area per unit time, g/cm^2/second.

b) The initial offgassing (e.g. light gases, H_2O, and volatiles) decay curve should be determined as a function of time over the temperature ranges anticipated. The anticipated precure or specific surface applications should be approximated.

c) Once the initial offgassing period has ended, the steady state outgassing rate should be determined over the temperature ranges anticipated. Additionally, the long term decay of the bulk outgassing rate at several temperatures is desirable.

d) The initial sticking coefficient as a function of the temperature of the source and the temperature of the collector should be determined over the range of temperatures anticipated.

e) At the end of each test, the collector should be incrementally heated to a temperature at least as high as the source to ascertain the permaneney and activation energy of the deposit.

f) Residual gas analysis should be acquired for all the above mass loss tests.

g) Ambient atmosphere readsorption quantities and subsequent behavior in vacuum as related to above testing should be determined.

h) Besides the testing of a material itself, there will be situations where geometry influences should be tested.

This will occur when a complex geometry is predominant such as the pallet graphite epoxy paneling or insulation blankets. A simulation of a representative configuration geometry should be tested (e.g. recent Shuttle Orbiter Thermal Protection System Tile testing at MSFC - Reference 19) for mass loss rate temperature and time dependence.

i) The infrared spectra and the spectral transmission or reflectance change of a given mass/unit area or thickness of the deposit should be measured.

j) Additional data is also desirable so that effects of the deposit and the source behavior can be ascertained. This would include environmental protons, electrons, and ultraviolet radiation and their effects on the source outgassing rate and Volatile Condensible Material (VCM) deposit characteristics.

This is not to imply that all Spacelab materials must be evaluated with the above considerations in mind but only those which by virtue of area of coverage, location, and/or possibly temperature profile may present a significant contaminant potential. With the wide variation in available data on the anticipated S13G thermal control paint to be used for the Spacelab configurations, it is recommended that the type of data indicated above be developed for this material so that this potential contaminant source can be properly evaluation and appropriate control measures can begin to be implemented.

An analysis was conducted to establish the contaminant impact of the Spacelab Avionics Bay Vent. This analysis indicated that the total mass and number column densities resulting from this vent were very close to being equal to those resulting from normal Spacelab module atmosphere leakage and an order of magnitude less than those resulting from the Shuttle Orbiter cabin atmosphere leakage. There appears to be adequate margin between the predicted column density and related control criteria. Total return flux at lower altitudes does exceed the criteria slightly. This should, in general, present no problem to Spacelab and Spacelab payloads due to the small percentage of effluent material that will condense at Spacelab/payload surface temperatures other than possibly exposed cryogenic surfaces. To preclude the release of internally generated particles from the Spacelab Avionics Bay Vent (e.g. dust, lint, paint flakes, etc.), the vent system should include filtration in its design. Since particles in the size range greater than or equal to 100 microns

have the capacity to impact scientific data of ultraviolet and infrared classes of scientific instruments, filtration of the Spacelab Avionics Bay Vent should be 100 microns or better.

As part of the modeling activity, two important aspects of the basic methodology underwent review and reassessment. These two aspects were the establishment of sticking coefficients of contaminants and the return flux methods of calculation for 2π steradian field-of-view surfaces. Clarification of the methodology for both of these aspects has been presented in this report. Activity was initiated to bring both of these aspects to a status where mutual agreement within the technical community can be achieved. Additional data as derived from future planned material tests to be conducted at MSFC along with contaminant self-scattering evaluations being planned should help provide supportive technology for these areas of basic contamination methodology.

1.3.1.3 Mission Profile Data Bank - A Mission Profile Data Bank (MPDB) was developed and formatted during this study. The MPDB identifies only the necessary contamination related data to provide mission requirements and profile changes in a consistent and timely fashion. The MPDB was formatted to accept any future mission development and identification. Specific mission related data as available in current program documentation has been catalogued for Missions 16, 10, 19a, and 12. The MPDB has been subdivided into four data files for utility and ease of formatting. These are the Spacelab Mission Data File (MDF), the Spacelab Payload Data File (SPDF), Spacelab Temperature File (STF), and the Mission Profile Description File (MPDF). The following data is contained in these files:

a) Spacelab Mission Data File (MDF)

   1) mission duration

   2) attitude and pointing requirements

   3) orbital altitudes

   4) observation requirements

   5) experiment/surface usage times

b) Spacelab Payload Data File (SPDF)

   1) Payload definition

   2) Spacelab/Shuttle Orbiter interface requirements

3) special subsystem requirements

c) Spacelab Temperature Data File (STDF)

1) thermal profiles

d) Mission Profile Description File (MPDF)

1) description of interfaces between data files a), b), and c) - annotation of final output

The MPDB was also subdivided into 4 separate data files in order to facilitate the necessary data requirements of different phases of the overall Spacelab Configuration Contamination Model. Where data was unavailable for specific portions of these files, data fields were allocated with TBDs to be replaced with data as it becomes available.

1.3.2 Spacelab Contaminant Induced Environment Prediction Summary - As a result of the modeling activity including the mentioned configuration/sources updates and the MPDB development, predictions were developed for the Spacelab contaminant induced environment. These predictions can be evaluated against the criteria as presented in References 1, 2, 3, and paragraph 1.10.4, ECR #EL52-0032, "Contamination Control Requirements." The criteria in Reference 1 and ECR #EL52-0032 were used as a basis for evaluation for this study. The ECR criteria are summarized below for comparison to the induced environment predictions.

a) Fewer than 1 particle larger than 10 microns in a 4 arc minute half angle field-of-view per orbit within 1 km.

b) Column density less than 10^{12} molecules/cm^2 for polar molecules.

c) Background brightness from scattering or emission less than 20th magnitude/arc sec in the near ultraviolet.

d) Return flux of less than 10^{12} molecules/cm^2/sec.

e) No more than 1 percent absorption from IR through UV by condensibles on optical surfaces.

Table I presents a summary status of the contaminant induced environment as it relates to the previous identified criteria. The table presents a judgment value with related comments as appropriate. Specific values for each Spacelab configuration evaluated (e.g. lines-of-sight, thermal profiles, attitudes, etc.) are contained in the text of the report under the appropriate subsections.

As noted in Table I, outgassing will meet the number column density criteria providing the outgassing rate of the modeled Spacelab thermal control coating demonstrates an effective outgassing rate of less than $6x10^{-9}$ g/cm^2/second at $100^{\circ}C$. This outgassing rate is equivalent to a maximum implied outgassing rate as inferred from percent weight loss screening criteria identified in 50M02442 Rev. W (Reference 7). This rate is also implied in SP-R-0022A (Reference 8) and ESRO PSS-09/QRM-02T (Reference 9) which provide similar guidelines (although not as restrictive in some cases) for material screening criteria as the 50M02442 document. Therefore, nonmetallic material testing to the 50M02442 document should be sufficient to meet the number column density for the evaluated S13G white thermal control coating.

In order to meet the return flux criteria, the outgassing rate will have to be less than 10^{-9} g/cm^2/second at $100^{\circ}C$ which is slightly better than the above mentioned maximum limiting rate inferred from the 50M02442 document. An outgassing rate of less than 10^{-13} g/cm^2/second at $100^{\circ}C$ will be required to meet a 1% absorption in the ultraviolet region for worst case on orbit conditions for a seven day mission. Through proper operational considerations such as mission timelining, spacecraft attitude and altitude, heaters for sensitive surfaces, design for small physical acceptance angles of instruments, and the use of protective covers, the allowable outgassing rate to meet the intent of this criteria may approach a rate compatible to those required to meet the number column density and return flux criteria. An additional option to meet the 1% absorption criteria would be to limit the location and percent of surface area covered with the nonmetallic thermal control coating. The conclusions stated in Table I are based upon the assumption that all external Spacelab surfaces are coated with S13G. Therefore, by eliminating or significantly reducing the use of such a nonmetallic coating on Spacelab, the 1% absorption criteria could most likely be met. As discussed in subsection 1.3.1.2,

Table I Status of Major Spacelab Sources as Compared to
Current Contamination Control Requirements

Contamination Control Criteria	Spacelab Contaminant Environment Prediction Status Summary
1) Fewer than 1 particle larger than 10 microns in a 4 arc minute half angle field-of-view per orbit within 1 km.	1) Can be met through proper timelining of the Spacelab Condensate Vent (SCV). Random particle emission appears acceptable assuming ground control used on Skylab (surfaces visibly clean and class 100K clean room control) results in Spacelab rates similar to those observed on Skylab.
2) Column density less than 10^{12} molecules/cm^2 for polar molecules.	2) Can meet intent of criteria providing: nonmetallic materials have outgassing rates less than 6×10^{-9} g/cm^2/second at 100°C (equivalent or more stringent than current materials screening criteria), operation of susceptible instruments is delayed 24 hours after launch for high offgassing to cease, and the SCV is properly timelined.
3) Background brightness from scattering or emission less than 20th magnitude/arc second in the near ultraviolet.	3) Spacelab can meet the intent of this requirement through proper SCV timelining.
4) Return flux of less than 10^{12} molecules/cm^2/second.	4) Intent of criteria can be met for most sources by: delaying exposure of susceptible surfaces 24 hours when offgassing decays to acceptable level; timeline SCV; and select nonmetallic materials with outgassing rates less than 1×10^{-9} g/cm^2/second at 100°C. Avionics Bay Vent or specification leakage will exceed criteria only at low altitudes (200 km). The intent of the criteria from these sources can be satisfied for susceptible surfaces by selecting higher altitudes, and/or by avoiding attitudes where the ambient drag vector is perpendicular to the surface, or through the use of protective devices as delineated in 5) below.
5) No more than 1 percent absorption from IR through UV by condensibles on optical surfaces.	5) For all sources except outgassing the intent can be met through proper timelining. For outgassing this criteria can be met if it were practical to select nonmetallic materials with rates less than 10^{-13} g/cm^2/second at 100°C. Otherwise, susceptible instruments will be required to furnish: their own protective covers; heaters for sensitive surfaces; and/or designs with small geometric acceptance angles for the sensitive exposed surfaces.

additional data will be required along with possible additional specific testing requirements to properly evaluate this source and subsequently implement meaningful control measures for the selection of nonmetallic thermal control materials for Spacelab.

A similar evaluation for offgassing indicated that this source would exceed the number column density, return flux, and in some cases for cryogenic instruments the 1% absorption criteria. The intent of the criteria could be met through establishing an initial 24 hour on orbit delay before initiating instrument or Payload operations. However, through obtaining specific test data as identified in subsection 1.3.1.2, the 24 hour operational delay can be reassessed.

Spacelab module cabin atmosphere leakage exceeds the return flux criteria, however, only approximately 2.1% of this material can condense at temperatures above cryogenically cooled surfaces. For the majority of Spacelab and Payload surfaces, these surfaces are at temperatures where the return flux would never be of concern. Under some select conditions, exposed cryogenic surfaces as associated with cooled infrared telescopes, could be of some concern and would have to be reviewed in more detail. The effects of this source could be further minimized through proper vehicle attitude selection.

An analysis was conducted to establish the contaminant impact of the Spacelab Avionics Bay Vent. This analysis indicated that the total mass and number column densities resulting from this vent were very close to being equal to those resulting from normal Spacelab module atmosphere leakage and an order of magnitude less than those resulting from the Shuttle Orbiter cabin atmosphere leakage. To preclude the release of internally generated particles from the Spacelab Avionics Bay Vent (e.g. dust, lint, paint flakes, etc.), the vent system should include filtration in its design. Since particles in the size range greater than or equal to 100 microns have the capacity to impact scientific data from ultraviolet and infrared classes of scientific instruments, filtration of the Spacelab Avionics Bay Vent should be 100 microns or better.

The only other source which exceeds the criteria is the Spacelab Condensate Vent (SCV). However, this is a liquid dump and can be effectively timelined or instrument constraints can be established to minimize the potential contaminant impact of this periodic vent.

One element in evaluating the Spacelab contaminant induced environment against the presented criteria is that the criteria is established as essentially the "maximum allowable" and in reality the contaminant induced environment is the sum total of a number of contributors or possible contributors. These contributors are:

a) all Spacelab configuration sources;

b) all Payload/instrument configuration sources;

c) all Shuttle Orbiter configuration sources;

d) all Solid Rocket Booster and staging rockets;

e) all External Tank ablation and venting;

f) all prelaunch conditioning;

g) all previous mission history; and

h) all subsequent achievable prelaunch conditioning.

In essence, no allowance has yet been made for budgeting of the criteria for different aspects of contamination control for the Shuttle Program. Therefore, some awareness to this factor must be allowed for when establishing the nature of the contaminant source and the requirements imposed to bring a contaminant source within criteria limits. This is not unique to Spacelab but is basic to the Space Shuttle Program.

1.3.3 <u>Mission Compatibility/Trade Study Summary</u> - The results of the basic modeling and model updates along with the determination of the contaminant induced environment has provided the basis for performing Spacelab mission compatibility analysis and trade studies. Spacelab mission compatibility

analyses were chronologically conducted for the following missions:

a) Mission 16 - High Energy Astrophysics;

b) Mission 10 - Pallet Flight Test Verification;

c) Mission 19a - Atmospheric, Magnetospheric, and Plasmas in Space; and

d) Mission 12 - Life Sciences Shuttle Laboratory.

A summary of the various contamination mission compatibility analyses is presented in Table II. The detailed evaluations for each of the above missions are contained in Appendices A through D respectively. The missions were evaluated against the contamination control criteria and where applicable brief comments and recommendations for contamination control are presented. These evaluations are reflective of peculiar or specific mission requirements imposed at the time of the analysis period of evaluation, complexity of the mission, available data, and level of effort for analysis. Some aspects of these missions will require additional evaluation and resolution in areas where contaminant potentials were identified but were not evaluated in detail due to the lack of available data or time.

As noted in Table II, many of the contaminant potentials can be minimized by employing operational constraints and/or changes in operational procedures. Unresolved for some of the missions are those areas of outgassing/offgassing which have been indicated as an area of concern where additional resolution from nonmetallic materials testing will be required. For these analyses, the baseline S13G mass loss rates used were those derived during the Skylab Program.

As part of evaluating the nonmetallic material impact on the Spacelab mission compatibility analysis, a trade study was conducted to establish the contamination impact of replacing the Spacelab aluminum honeycomb panels on the pallets with graphite epoxy carboform 69. Two conditions were considered. These were 1) replacement of the S13G coated aluminum honeycomb panels directly and 2) replacement of the aluminum honeycomb panels

Table II. Mission Compatibility Analysis Summary

MISSION	MISSION COMPATIBILITY ANALYSIS SUMMARY
Mission 16 - High Energy Astrophysics	o Shuttle Orbiter OMS firings can slightly degrade the Spacelab carrier and scientific instrument thermal control systems. Payload bay doors should be closed during these burns. o VCS firings will exceed the 10^{12} polar molecules/cm^2 criteria for CMG desaturation maneuvers. Scientific instruments can be timelined. o For VCS attitude control, the VCS firings will exceed the 10^{12} polar molecules/cm^2 criteria. However, this should not impact the high energy astrophysic instruments' ability to collect data. o Particulate production by the VCS is yet to be established.
Mission 10 - Pallet Flight Test Verification	o Shuttle Orbiter OMS firings can slightly degrade the Spacelab carrier and scientific instrument thermal control systems. Payload bay doors should be closed during these burns. o Deposition as a result of outgassing on the SO-703 coelostate will exceed the 1% absorption criteria in the ultraviolet in approximately the first two orbits of exposure. Use of design considerations such as remote covers, heaters, physical acceptance angle restrictions and operational considerations such as proper attitude and orbital altitude considerations will minimize this contaminant effect. o The 10^{12} polar molecules/cm^2 criteria will be exceeded by the VCS, evaporator, and outgassing/offgassing. The total impact of this is unknown but is expected to be small. o Random particle sloughing (based upon observed Skylab data) will meet the criteria of less than 1 particle larger than 10 microns in a 4 arc minute half angle field-of-view per orbit within 1 km. However, false stars may be detected by the star trackers which will require proper bright target star selection and/or limiting the frequency of operational updates.

Table II. Mission Compatibility Analysis Summary (continued)

Mission 19a - Atmospheric, Magnetospheric, and Plasmas in Space (AMPS)	o Active vents in the Shuttle Orbiter should be closed during SRB separation and all sensitive experiments (e.g. remote sensing platform and Lidar) should be covered. o Shuttle Orbiter OMS firings during launch and especially during retro burns can appreciably degrade exposed Spacelab and scientific instrument thermal control systems. Payload bay doors should be closed during these burns. o Significant levels of deposition from outgassing have been predicted for the scientific instruments and windows which exceeds the 1% absorption criteria in the ultraviolet. The intent of the 1% absorption criteria can be approached by closing scientific instrument and window covers when not in use, proper timelining, and attitude and altitude selection (except for the ultraviolet experiments exposed more than a few orbits). This deposition will also degrade thermal control system's solar absorptivity by as much as 0.19 from ultraviolet photopolymerization of the deposits on the Spacelab pallet and as much as 0.16 for the module. Thermal control system tolerance to this degradation will be required to assess this effect totally. o All Shuttle Orbiter and Spacelab sources exceed the 10^{12} polar molecules/cm^2 criteria under certain conditions. The intent of the criteria can be met through proper operational timelining and constraints. o Ambient ion probes and mass spectrometers measuring near the Shuttle Orbiter ambient environment will be significantly degraded by the contaminant induced environment even with the implementation of operational timelines and constraints. These instruments could be placed on subsatellites at distances greater than 80 to 180 meters, depending upon the orbital altitudes, for the contaminant flux to be less than 10% of the ambient environment for certain molecular species. o Random particle sloughing (based upon observed Skylab rates) will meet the applicable criteria for particle sloughing. However, particle generation from the Shuttle Orbiter VCS, RCS, and evaporator is yet to be established.

Table II. Mission Compatibility Analysis Summary (concluded)

Mission 19a - (continued)	o Other areas of concern include subsatellite impacts (hydrazine thrusters impinging upon the Spacelab carrier and Shuttle Orbiter and RCS impingement upon the subsatellite), charging effects from ion and electron accelerators enhancing contaminant deposition, and chemical releases in the near vicinity of the spacecraft. o The large number of planned missions for this payload will require covers or protective devices to be used during reentry.
Mission 12 - Life Sciences Shuttle Laboratory	o Deposition from outgassing on Spacelab carrier and scientific instrument thermal control surfaces can result in a solar absorptivity change of approximately 0.05. This should present no problem for this mission but must be considered in scientific instrument design and refurbishment requirements for subsequent missions. o Covers were not identified for the TOBE and SEXSAT satellites and are recommended for on orbit to meet the 1% absorption criteria. These covers would also prevent any launch affects upon them. In addition, SEXSAT degradation from deposition can be minimized by early mission deployment. o During deployment, VCS and RCS firings should be constrained to minimize potential deposition upon the SEXSAT external surfaces. In addition, SEXSAT solid rocket deployment motors present a severe contaminant potential. Proper deployment procedures will be required to avoid Spacelab and Shuttle Orbiter impingement. o TOBE should employ protective covers for critical optics during reentry to minimize refurbishment requirements.

with painted S13G thermal control paint over the epoxy carboform 69. For case 1, the results indicated that the contamination impact of replacing the aluminum honeycomb panels on the pallet structures with graphite epoxy carboform 69 should be negligible to the total induced environment for the modeled Spacelab configurations. Where the epoxy carboform 69 is painted with S13G paint, the mass loss of the S13G dominates the final results significantly and still exceeds the related contamination control criteria. Therefore, using epoxy carboform 69 in place of the aluminum honeycomb panels on the pallets does not significantly impact the resulting induced environment under the guidelines used in this study.

In the performance of the above studies, incompatibilities in published contamination control requirements for the Spacelab and Shuttle Program were noted. These incompatibilities are discussed in subsection 3.1-f in the report. The incompatibilities relate to interpretation of stated control requirements that could infer the opposite meaning to that intended and that in some cases the contaminant level can be greater than the requirement without indicating how much the requirement can be exceeded. It was not the intent of the activity conducted under this study to recommend new or different requirements. It is only pointed out what appears to be incompatibilities between existing published criteria so that, as necessary, program review may be initiated to further increase the utility of these criteria and their impact upon effectively implementing Spacelab contamination recommendations for improvements.

The effectiveness and timeliness of the contamination modeling and analysis is a direct function of the resolution and quality of the available configuration and contamination sources data. Throughout the course of this study, several areas requiring supplemental data have been identified which would enhance the contamination analysis being conducted. Those areas that are related to ESRO supplied information include:

a) materials mapping of all major external nonmetallic materials (greater than 0.1 m^2 in area) to be used on the Spacelab configurations including locations, area of coverage, and available outgassing/offgassing data;

b) current design, location, and operational timelines of the Spacelab Condensate Vent including vent direction, flowrates, and exit orifice design;

c) the maximum allowable degradation for Spacelab thermal control surfaces including pallet degradation tolerances to insure the proper thermal balances during reentry;

d) the constituents and leakage flowrates of the Igloo system purge gases; and

e) outgassing and offgassing rate data consistent with the recommended test requirements itemized in Section 1.3.1.2 for the thermal control coating as applied to Spacelab.

Those areas related to NASA supplied data and information include:

a) updated thermal profile data for the SMTP and FP Spacelab configurations consistent with data received for the LMOP configuration;

b) S13G materials outgassing and offgassing data consistent with the recommended test requirements itemized in subsection 1.3.1.2 resulting from planned testing of this material at the Materials and Processes Laboratory at MSFC;

c) updated approved Contamination Control Requirements as determined by the CRDG at MSFC;

d) modifications to the SSPD (References 2 and 3) inflight contamination control criteria resulting from comments contained in subsection 3.1-f;

e) detailed data on scientific instrument designs and sensitivities and mission on orbit operational timelines and procedures such as deployment and retrieval schemes, etc.;

f) status of any Engineering Change Requests (ECRs) pertaining to contamination analysis including Spacelab/ Shuttle Orbiter configuration and sources modifications; and

g) when available, data acquired by the inflight contamination monitoring package and other contamination data determined during the early Spacelab flights from witnessed Spacelab and scientific instrument degradation.

Receipt of this data, where applicable, should be consistent with scheduled Spacelab program milestones. For this reason, it would be desirable to have design and test information at least two months prior to the Preliminary Design Review scheduled for December 1975. Operations data should be made available at least two months prior to the Operations Requirements Review scheduled in June 1976 although it would be highly desirable to have it before the Pre-operations Requirements Review in September 1975.

2. STUDY RESULTS

2.1 Modeling Activities - The general modeling considerations and approaches utilized in this study are identical to those used in previous studies in establishing the Spacelab and the Shuttle Orbiter contamination models described in References 4, 5, and 6. This section contains a brief description of the current modeled Spacelab configurations and contamination sources along with those identified modifications, additions, and updates that have been incorporated during this contract period. The changes reflect the most currently identified technology and available Spacelab and Shuttle Orbiter source and configuration data. Also included herein is a discussion of the status of the Mission Profile Data Bank (MPDB) and the program logic flow involved in its integration into the Spacelab Configuration Contamination Model (SCCM).

2.1.1 Modeled Spacelab Configurations and Contamination Sources - The current Spacelab Configuration Contamination Model consists of three Spacelab configurations deemed representative of the many various hardware combinations possible with the highly adaptable Spacelab carrier system. These configurations

include: 1) the Long Module/One Pallet (LMOP); 2) the Short Module/Three Pallet (SMTP); and 3) the Five Pallet (FP) systems. The basic configuration data was extracted from Reference 10 in which the highest resolution data was presented for the LMOP configuration. The LMOP configuration was used as the baseline reference configuration for geometric considerations in the modeling. Figure 1 presents this configuration illustrating the basic hardware elements of the Spacelab carrier from which the SMTP and FP configurations were constructed. It should be noted that the axis system depicted and the station numbers referenced are consistent with those of the Shuttle Orbiter coordinant system and are utilized throughout this study.

Graphic displays of the three modeled configurations as drawn by the computer are presented in Figures 2 through 4. These displays have been annotated with the major contamination source locations. Note, that all three configurations are positioned in the Shuttle Orbiter payload bay within an envelope between $X_o = 582$ and 1215.2. This was done for consistency and to allow adequate room between $X_o = 1215.2$ and 1307 for auxiliary propellant tanks required for certain Spacelab missions.

As illustrated, the line-of-sight origin for each configuration is positioned at the center point along the X axis of each of the respective pallet assemblies. The contamination model induced environment predictions for representative optical instruments located at the line-of-sight origin are used as the basis for the evaluation studies conducted. Lines-of-sight are gimballed around this origin point to encompass a 100 degree conical viewing volume above the Spacelab pallet as illustrated in Figure 5 for the SMTP configuration. This 100 degree cone encompasses the viewing requirements of the majority of Spacelab Payloads to be flown.

To date 5 major contaminant sources have been identified for the modeled Spacelab assemblies. These are: 1) nonmetallic materials outgassing (bulk weight loss characteristic); 2) materials offgassing (initial high weight loss of light gases and volatiles); 3) cabin atmosphere leakage (crew modules and tunnel sections); 4) the Spacelab Condensate Vent (SCV); and 5) the Avionics Bay Vent. Locations of these sources are

Obtained from
Reference 10

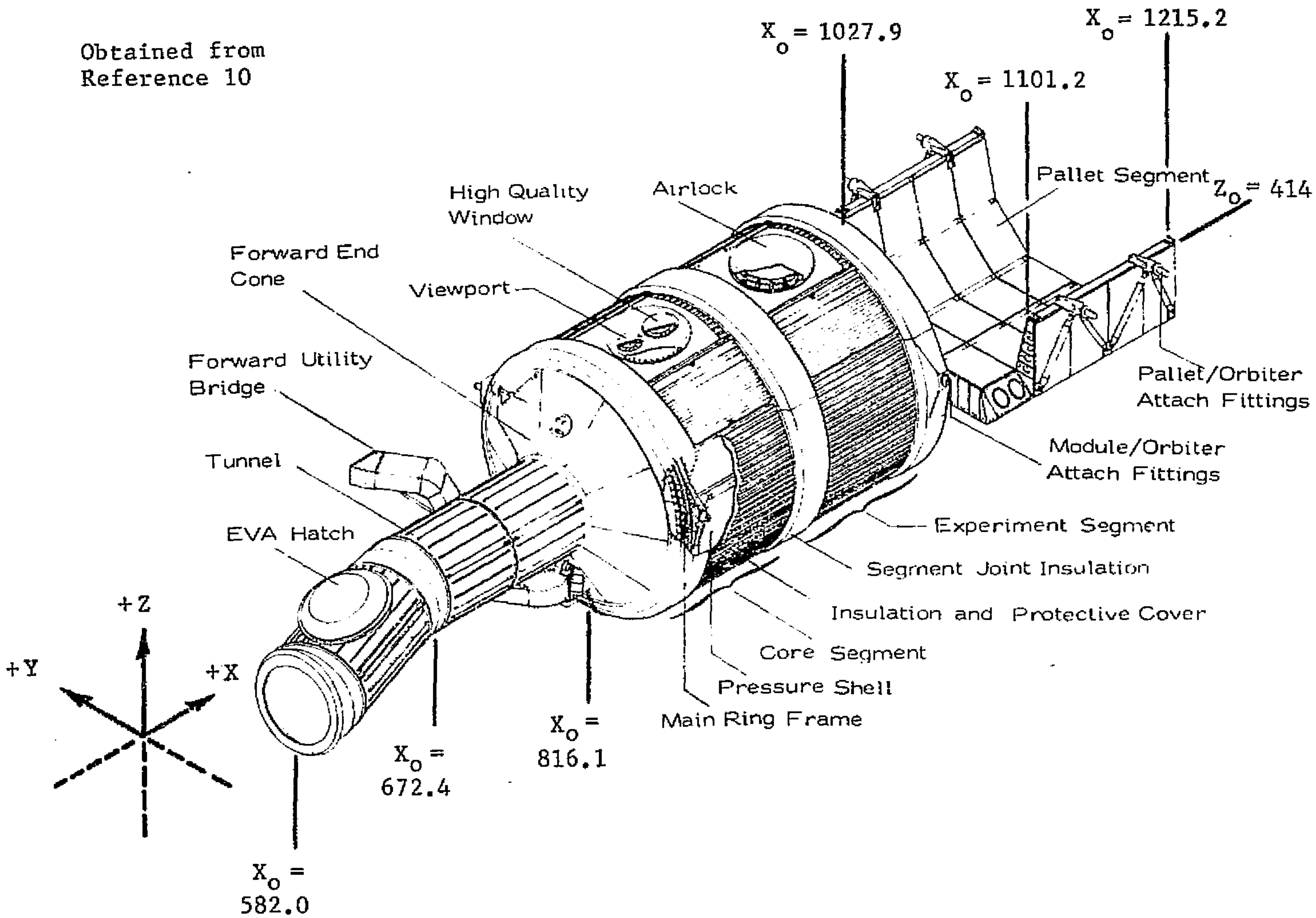


Figure 1. Baseline Long Module/One Pallet Reference Spacelab Configuration (LMOP)

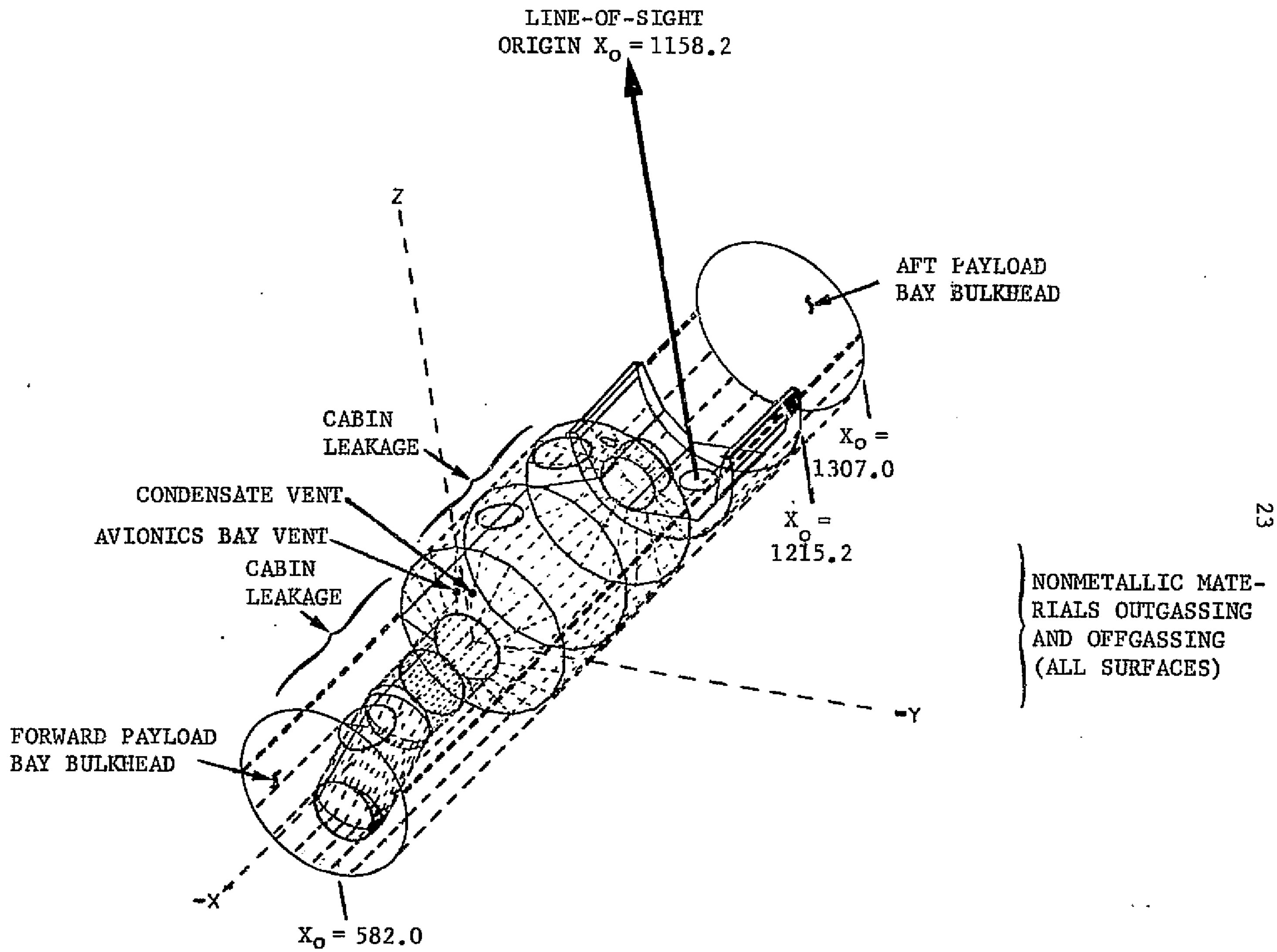


Figure 2. Computer Drawing of the Long Module/One Pallet Spacelab Configuration (LMOP)

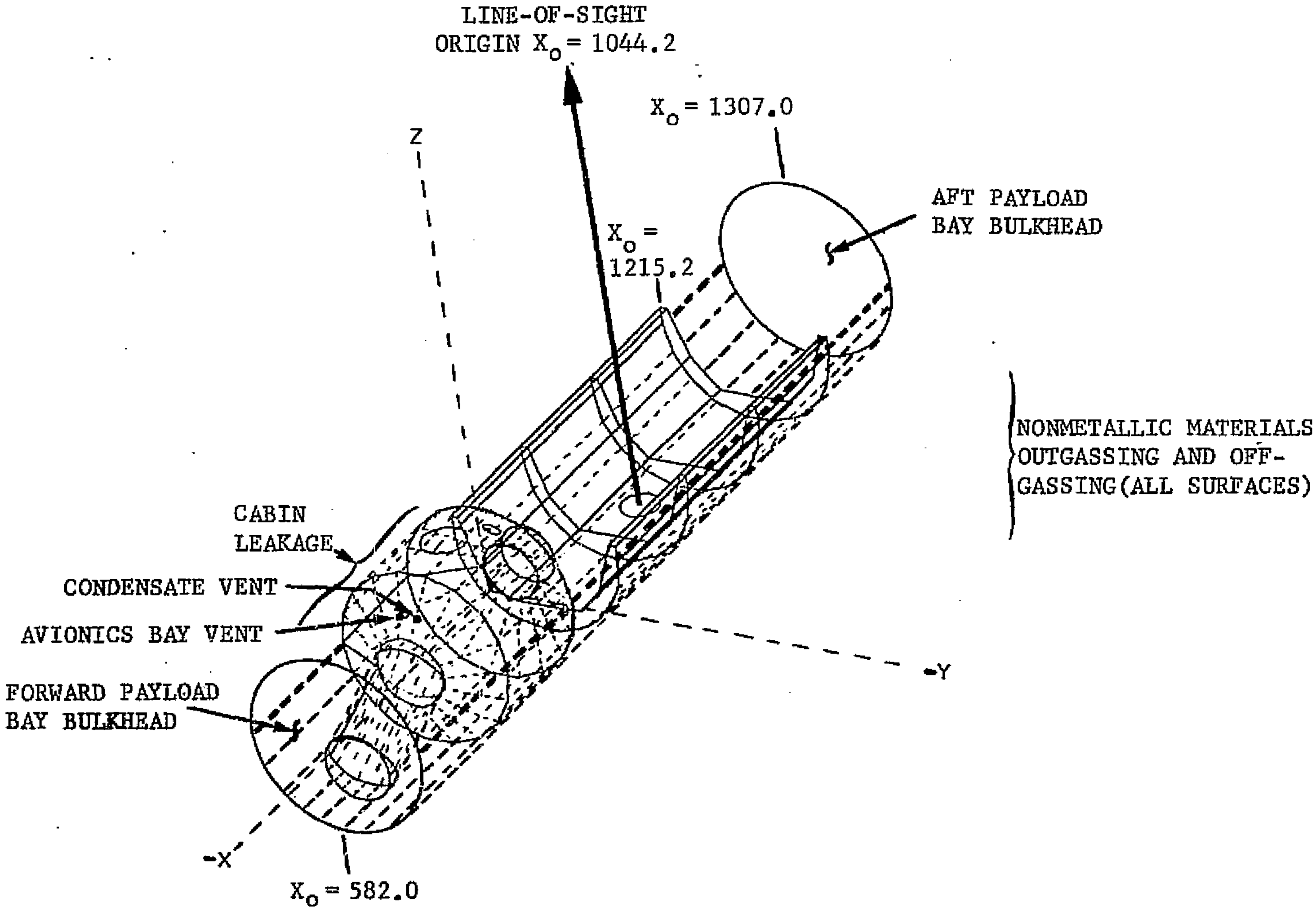


Figure 3. Computer Drawing of the Short Module/Three Pallet Spacelab Configuration (SMTP)

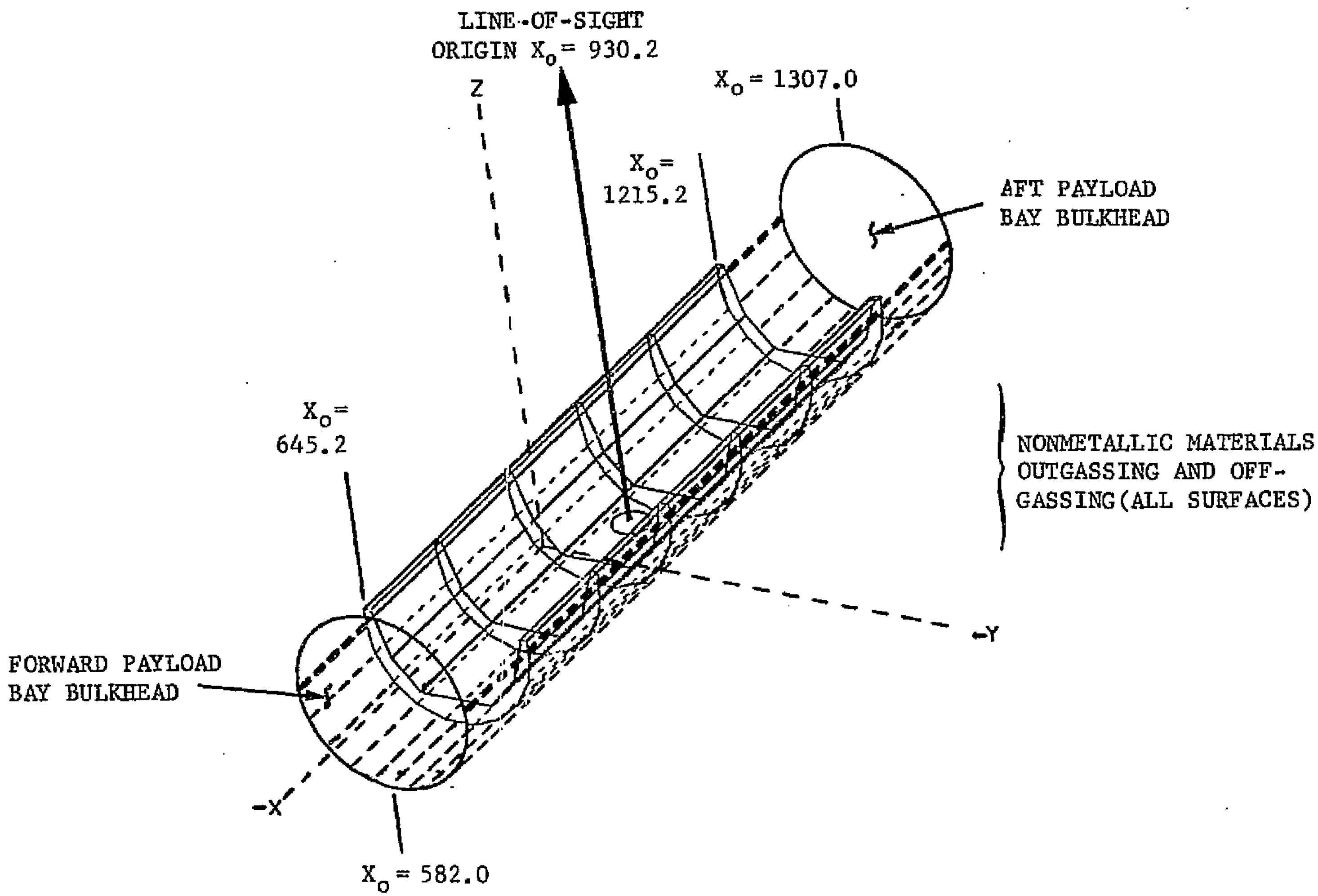


Figure 4. Computer Drawing of the Five Pallet Spacelab Configuration (FP)

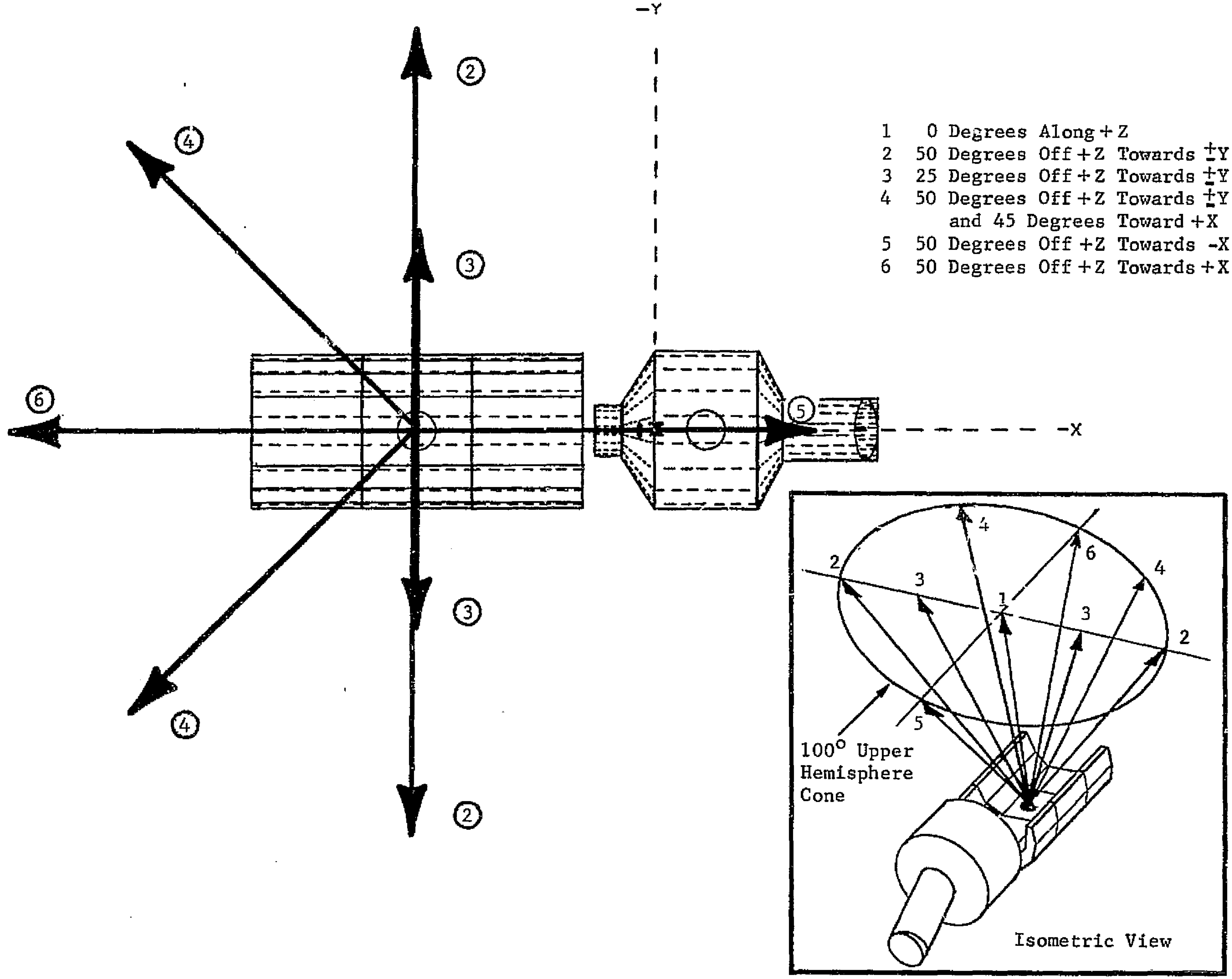


Figure 5. Lines-of-Sight for the SMTP Spacelab Configuration

illustrated in Figures 2 through 4 for the three modeled configurations. Table III presents a parametric summary of the major Spacelab sources which identifies the assumptions and the methodology utilized in modeling them. Additional information pertaining to this table and these sources is briefly discussed below.

Nonmetallic materials outgassing is modeled as a continuous Lambertian contaminant source with a rate that is a direct function of surface temperature (T in ^{o}C) and time (t in hours) of exposure to the vacuum environment of space. Available data from ESRO (Reference 11) indicates that the solar oriented surfaces will be painted with a white thermal control coating denoted S13G. Materials mapping of other Spacelab nonmetallics is not yet available and will be required from ESRO as these studies continue. The model, therefore, assumes that all Spacelab surfaces are coated with S13G. Outgassing rate data utilized as a basis for the analysis in this study was derived from materials testing by Ball Brothers Research Company (Reference 12) during the Skylab Program. The modeled baseline outgassing rate at $100^{o}C$ is 1×10^{-8} g/cm^2/second (for presentation purposes, baseline outgassing and offgassing rates are identified at $100^{o}C$ while during the analysis these rates vary as a function of surface temperature and are established by the computer model) and varies with surface temperature as $e^{(T-100)/29}$. Based upon observed inflight Skylab data, the outgassing rate is modeled to vary with exposure time as $e^{-t/4100}$ (which equates to a near constant rate over seven to thirty day Spacelab missions). The fraction of outgassed material impinging upon a surface that sticks (i.e. the sticking coefficient) is determined by the temperature difference between the outgassing surface and the surface impinged upon divided by 200 when the outgassing surface is warmer ($S = \Delta T/200$). The rationale for this expression is discussed in detail in subsection 2.1.3.1-d.

A similar approach is utilized in modeling the materials offgassing phenomena. However, in contrast to outgassing, the offgassing rate decays rapidly upon initial exposure to space vacuum falling below the outgassing rate in 50 to 60 hours and essentially disappearing after approximately 100 hours based upon the expression $3.87e^{-0.14t} + 3.0e^{-0.055t}$ with t in hours of exposure. The modeled offgassing rate at $100^{o}C$ is 2.5×10^{-7} g/cm^2/second at 10 hours into this decay curve. The 10 hour

Table III. Summary Table for Major Spacelab Sources

Major Sources	Modeled Location	Duration/ Frequency	Flowrate	Constituents	Plume Shape Function	Velocity	Size Parameter
Outgassing	All External Spacelab Surfaces	Continuous	$1\times10^{-8} e^{-t/4100}$ $e^{(T-100)/29}$ g/cm^2/second	Hydrocarbon chain fragments, RTV's, etc.	$\cos \theta/r^2$	$12.9 \sqrt{T(^{\circ}K)}$ m/second	Molecular average M=100
Offgassing	All External Spacelab Surfaces	Continuous for the first 100 hours on orbit	$3.87e^{-0.14t}$ $+3.0\ e^{-0.055t}$ $e^{(T-100)/29} \times 10^{-7}$ g/cm^2/second	Water, Light Gases, Volatiles	$\cos \theta/r^2$	$30.4 \sqrt{T(^{\circ}K)}$ m/second	Molecular average M=18
Cabin Atmosphere Leakage	Pressurized Module/ Tunnel Surfaces (Excluding Igloo)	Continuous	1.35 kg/day	O_2 N_2 CO_2 H_2O	$\cos \theta/r^2$	$2220 \sqrt{\frac{T}{M}}$ m/second	Molecular average M=29
Spacelab Condensate Vent	Module forward end cone - venting 45° off +Z towards -X in the X,Z plane	Once every seven days for 32 minutes	0.91 kg/minute (35 kg/dump)	Water	Empirical 65° half angle	7 m/second	Particles 30μ to 900μ radius
Avionics Bay Vent	Module forward end cone - venting 45° off +Z towards -X in the X,Z plane	Continuous	1.35 kg/day	O_2 N_2 CO_2 H_2O	$\cos \theta/r^2$	$2220 \sqrt{\frac{T}{M}}$ m/second	Molecular average M=29

M = Molecular weight
T = Temperature ($^{\circ}$C unless noted)
t = time (hours) of vacuum exposure
θ = Angle (degrees) off surface normal or plume centerline
r = Distance (cm) from emitter to receiver

point is considered as that elapsed time on orbit when activation of susceptible instruments might be expected to occur.

Cabin atmosphere leakage is limited to the pressurized volumes of the Spacelab configurations with the exception of the Igloo. When leak rate data for the Igloo is received from ESRO, it will be incorporated into the model. For those pressurized volumes, leakage is modeled as a Lambertian source being emitted uniformly from their external surfaces.

The Spacelab Condensate Vent (SCV) final design is yet to be determined. However, indications are that it will be similar to the contingency condensate vent utilized on Skylab and tested during the Skylab Contamination Ground Test Program (SCGTP) at Martin Marietta. The parameters in Table III for the SCV reflect the SCGTP results. Because a large portion of the SCV vent plume will impinge upon the Shuttle Orbiter forward bulkhead (Reference 5), it has been recommended that this vent be relocated. Further analysis is pending a response by ESRO.

The Avionics Bay Vent demonstrates a relatively low, continuous flowrate and is, therefore, modeled as a Lambertian source centered around the vent centerline.

2.1.2 Configuration Updates - Concurrent with the activities performed for this study, changes to the basic Spacelab and Shuttle Orbiter contamination modeled configurations have been made to improve the fidelity of the composite contaminant induced environment predictions. The following subsections contain a brief discussion of the incorporated configuration updates for both the Spacelab and Shuttle Orbiter models respectively.

2.1.2.1 Spacelab Model Configuration Updates - Throughout the course of this study, several modifications were made to the basic Spacelab modeled configurations which ultimately impacted the induced environment predictions for those affected configurations. These modifications or updates included 1) increasing the number of the SMTP configuration lines-of-sight; 2) incorporation of updated maximum and minimum temperature data for the LMOP configuration; and 3) addition of the Avionics Bay Vent to the SMTP and LMOP pressurized modules.

a) SMTP Lines-of-Sight Updates - During the period of activities covered in the previous Spacelab contract (Reference 5), only the +Z or zero degree line-of-sight was established for the SMTP Spacelab configuration for determining mass and number column densities and return flux predictions. This was originally done for comparison purposes with the established predictions of the LMOP and the FP Spacelab configurations. The LMOP and FP configurations had been modeled with nine lines-of-sight encompassing a 100 degree conical volume above the center of the respective pallet assemblies. These two configurations were initially chosen for detailed analysis since they represented the largest geometric variance and hence the widest variance in potential contamination influence upon the Spacelab induced environment. However, for completeness of the contamination prediction data base and due to the fact that missions analyzed in this study such as the Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) mission employed the SMTP Spacelab configuration, eight new lines-of-sight were established which encompass the 100 degree conical section centered around the zero degree line-of-sight. These are illustrated graphically in Figure 5 and include:

1) fifty degree lines-of-sight (4 directions, 50 degrees off the +Z toward the 4 orthogonal axes);

2) twenty-five degree lines-of-sight (2 directions, 25 degrees off the +Z toward the $\pm$Y); and

3) forty-five degree lines-of-sight (2 directions, 50 degrees off +Z and 45 degrees off $\pm$Y toward +X).

The lines-of-sight depicted in Figure 5 are consistent with those of the LMOP and FP configurations and can be used as reference for these Spacelab configurations as well.

The results of this effort are reflected in the induced environment prediction tables presented later in this section and in the subsequent conducted mission compatibility studies.

b) LMOP Thermal Profile Update - In response to the requirement for higher resolution thermal profile data for the Spacelab configurations modeled, updated temperature predictions resulting from analysis conducted by Teledyne Brown Engineering (Reference 13) have been incorporated into the LMOP configuration. This data included Spacelab surface temperatures for the maximum hot case attitude (+Z solar inertial, Y local vertical, 100% solar exposure), and the minimum cold case attitude (+X, i.e. aft side, solar inertial; -Z local vertical). These attitudes encompass the Spacelab temperature extremes and consequently encompass the maximum and minimum outgassing and offgassing periods of the Spacelab vehicle. This data indicates that Spacelab LMOP surface temperatures vary between the extremes of $-193^{o}C$ and $+88^{o}C$ for these two attitudes. It has been deemed more practical to utilize these extremes in the contamination model predictions rather than attempting to interpolate temperatures for various beta angles as was performed for Skylab. This will tend to simplify the tabular presentations of the huge amounts of prediction data without loosing the utility and fidelity of the predictions. It also will retain consistency between the predictions and the format of the available thermal data. Therefore, the ensuing model predictions will be formatted for maximum and minimum extremes from materials outgassing and offgassing.

The Teledyne Brown thermal model utilizes a Spacelab nodal configuration similar to the Spacelab Configuration Contamination Model with higher fidelity for certain geometric surfaces. For compatibility, and due to the fact that each modeled nodal surface has its own unique thermal profile, the Spacelab LMOP contamination configuration was subdivided into 47 nodes, as compared to the previous 22 nodes, and new view factors were calculated for the LMOP configuration lines-of-sight.

New outgassing and offgassing runs were made using the updated thermal data and the resulting predicted column densities and return flux rates decreased by approximately one half from previous predictions for the lines-of-sight analyzed. This is reflected in the outgassing and offgassing tables contained later in this section. Updated thermal profile data is not yet available for the SMTP and FP Spacelab configurations. However, when this data is received, it will be incorporated into the model as was the LMOP thermal data. It is anticipated that similar decreases in the predicted levels of contamination will be observed when this data is integrated into the remaining configurations. Thermal profile data currently being used for these configurations was obtained from Reference 11 which indicates surface temperature extremes of $-142^{\circ}C$ to $+106^{\circ}C$ for the SMTP and $+8^{\circ}C$ to $+40^{\circ}C$ for the FP configuration.

c) Avionics Bay Vent - The final major modification to the modeled Spacelab configurations involved the addition of the Avionics Bay Vent system to the LMOP and SMTP pressurized modules. The Avionics Bay Vent is located on the Spacelab core module forward taper in the (X, Z) plane oriented approximately 45 degrees off of the +Z axis toward the -X axis. Its major vent effluents will be the constituents of the Spacelab cabin atmosphere. Due to the relatively low flowrate of this vent (1.35 kg/day), the flowfield has been modeled as a Lambertian source (with a $\cos \theta/r^2$ plume distribution). A detailed analysis of this vent system is contained in subsection 2.2.2.

2.1.2.2 Shuttle Orbiter Model Configuration Updates - Several additional modifications and updates were made under the concurrent JSC (Reference 6) activity to the basic Shuttle Orbiter configuration which have direct or indirect influence upon the contaminant environment prediction for Spacelab hardware and its scientific instruments. These included:

a) increasing the fidelity of the Shuttle Orbiter tail section (Since the tail has direct lines-of-sight to the hardware flown in the payload bay, increased fidelity

was necessary to determine surface-to-surface deposition phenomena.);

b) increasing the fidelity of the Orbital Maneuvering System (OMS) pod structure (This was necessary for surface-to-surface deposition predictions and for more accurate shadowing considerations of the OMS and VCS engines from Spacelab/Payload surfaces.); and

c) adding the "split door" configuration to the forward payload bay doors (This was necessary to increase the accuracy of predicting contributions from sources such as the VCS and evaporator which reflect off of the Shuttle Orbiter wing structures.)

2.1.3 Sources Updates - Certain adjustments, additions, and modifications were made to the basic Spacelab and Shuttle Orbiter contamination source characteristics for input into the respective models. In addition, investigations into refinements of the methodology utilized in describing and modeling certain contamination phenomena were initiated. These items are discussed, where applicable, for the Spacelab and Shuttle Orbiter models respectively in the following subsections along with their ultimate impacts to the determined induced environment predictions. Unless otherwise noted, these modifications are all reflected in the contamination analyses contained in this report.

2.1.3.1 Spacelab Model Sources Updates - The major updates and methodology refinements associated with the modeled Spacelab contamination sources included 1) outgassing and offgassing rate adjustments for the primary Spacelab external white thermal control coating; 2) incorporation of a refined method of determining return flux to large field-of-view surfaces (2π steradian fields-of-view); and 3) clarification and investigation of the methods employed in determining the sticking coefficient between an outgassing contaminant source and surfaces upon which it might impinge.

a) S13G White Thermal Control Paint Source Evaluation - The Spacelab Configuration Contamination Model currently considers that all of the +Z facing externally exposed Spacelab carrier surfaces are coated with S13G (a white thermal control coating which is composed of zinc oxide pigmented RTV 602 which characteristically demonstrates a loss of mass when exposed to space vacuum). This is

considered as the primary nonmetallic Spacelab contaminant source contributer to the induced contaminant environment. The baselined mass loss rates for this material as used in the ensuing Spacelab contamination analyses are the same as were utilized in the previous Spacelab contamination analysis report (Reference 5). That is, a steady state outgassing rate of $1x10^{-8}$ g/cm^2/second at 100^{o}C and an offgassing rate at 10 hours into the mass loss decay curve of $2.5x10^{-7}$ g/cm^2/second at 100^{o}C. The 10 hour point was chosen to be indicative of that time after launch when on orbit checkout of systems and operational activities might be expected to commence.

Data recently made available from extensive materials testing of the S13G used on the Skylab Apollo Telescope Mount (ATM) canister by the Materials and Processes Laboratory at MSFC (Reference 14) indicates the following source rate data:

Steady state outgassing rate = $2.7x10^{-12}$ g/cm^2/second at 100^{o}C

Initial high weight loss rate (offgassing) = $2.5x10^{-10}$ g/cm^2/second at 100^{o}C for the first 22 minutes.

This data varies significantly from the current modeled baseline values. The tested S13G underwent extensive batch control and precuring with the prime objective of minimizing the outgassing rate of the ATM canister. Therefore, the values should be near "best case" for S13G paint. The test samples were vacuum-baked for a period of 48 hours at 200^{o}F prior to conducting the S13G outgassing and offgassing tests. Whether or not the Spacelab vehicle as a whole will be subjected to similar curing cycles as were the ATM test samples is currently unknown. However, it is anticipated that this may not be the case.

It is apparent that, due to the large deviations in data, additional materials testing which would be representative of the Spacelab unique parameters might be required for the characteristic Spacelab S13G (or any other coating which might ultimately be used in its place). This testing should establish more representative source rate data in a form which can be easily integrated into the contamination model and subsequently evaluated. It is realized that improvements have been made to the S13G coatings over the levels currently used in the model and that the data supplied by the MSFC Materials and Processes Laboratory from ATM testing is probably near the lowest value achievable. The source rates for the actual material to be used on Spacelab will most likely fall between these two extremes. As such, a test program is currently under consideration at the Materials and Processes Laboratory at MSFC. Agreement has been reached with this laboratory that the following data should be furnished for refinement of available source rate data as well as supplying any necessary modifications to the basic methodology employed in the modeling activities.

1) All outgassing data should be supplied in the form of mass loss per unit area per unit time, $g/cm^2/second$.

2) The initial offgassing (e.g. light gases, H_2O, and volatiles) decay curve should be determined as a function of time over the temperature ranges anticipated. The anticipated precure or specific surface applications should be approximated.

3) Once the initial offgassing period has ended, the steady state outgassing rate should be determined over the temperature ranges anticipated. Additionally, the long term decay of the bulk outgassing rate at several temperatures is desirable.

4) The initial sticking coefficient as a function of the temperature of the source and the temperature of the collector shculd be determined over the range of temperatures anticipated.

5) At the end of each test, the collector should be incrementally heated to a temperature at least as high as the source to ascertain the permanency and activation energy of the deposit.

6) Residual gas analysis should be acquired for all the above mass loss tests.

7) Ambient atmosphere readsorption quantities and subsequent behavior in vacuum as related to above testing should be determined.

8) Besides the testing of a material itself, there will be situations where geometry influences should be tested. This will occur when a complex geometry is predominant such as the pallet graphite epoxy paneling or insulation blankets. A simulation of a representative configuration geometry should be tested (e.g. recent Shuttle Orbiter Thermal Protection System Tile testing at MSFC) for mass loss rate temperature and time dependence.

9) The infrared spectra and the spectral transmission or reflectance change of a given mass/unit area or thickness of the deposit should be measured.

10) Additional data is also desirable so that effects of the deposit and the source behavior can be ascertained. This would include environmental protons, electrons, and ultraviolet radiation and their effects on the source outgassing rate and Volatile Condensible Material (VCM) deposit characteristics.

For comparative purposes, updated induced environment predictions were made for the three Spacelab configurations based upon the two existing sets of S13G mass loss data. These predictions reflect the most recent Spacelab configuration updates mentioned in Section 2.1.2.1 including the Spacelab LMOP thermal profile update and the additional Spacelab SMTP lines-of-sight.

Tables IV through VI present a comparative summary of the outgassing induced environment predictions for the three modeled Spacelab configurations. For the nine major lines-of-sight, the mass and number column densities and the molecular return flux for the orbital altitudes of 700, 435, and 200 km are presented. The return flux predictions are based upon an acceptance angle relationship at the center point of each Spacelab configuration pallet assembly of 0.19 steradians. The data presented is for the maximum (hot case) and minimum (cold case) temperature extremes that the Spacelab vehicles might be expected to experience (remembering that the LMOP configuration has the updated thermal data factored into its calculations.

For the baseline Spacelab outgassing rate of 1×10^{-8} g/cm^2/second at $100^{\circ}C$, the predicted number column densities (NCD) for certain lines-of-sight of the Spacelab LMOP and SMTP configurations approach or slightly exceed the NCD limit of 10^{12} polar molecules/cm^2 as stated in Reference 1. This is also true for the return flux criteria of 10^{12} molecules/cm^2/second at altitudes between approximately 250 km and 350 km. In contrast, the induced environment predictions in Tables IV through VI for the ATM type S13G outgassing rate of 2.7×10^{-12} g/cm^2/second at $100^{\circ}C$ meet both the NCD and return flux criteria at all altitudes and anticipated temperature extremes. This comparison serves to further illustrate the need for some additional materials testing of the major nonmetallic materials to be used on Spacelab.

The return flux at 200 km is attenuated to approximately zero due to the fact that at this altitude, the mean free path of the outgassed molecules is essentially so short, approximately 1 meter, that the outgassing molecules are unable to travel far enough into the ambient drag vector to be reflected back to Spacelab/Payload surfaces.

Table IV. Outgassing Induced Environment Rate Comparison Predictions for Spacelab LMOP Configuration

Predicted Parameters / Line-of-sight/ Temperature	Outgassing Rate(1) = 1.0×10^{-8} g/cm^2/second at 100°C					Outgassing Rate(2) = 2.7×10^{-12} g/cm^2/second at 100°C				
	MCD (g/cm^2)	NCD ** (mol/cm^2)	Return Flux(Max) (mol/cm^2/second)			MCD (g/cm^2)	NCD ** (mol/cm^2)	Return Flux(Max) (mol/cm^2/second)		
			700 km	435 km	200 km			700 km	435 km	200 km
0° +Z										
Max	1.1(-10)*	6.8(+11)	1.1(+10)	3.1(+11)	Negligible	3.0(-14)	1.8(+8)	3.1(+6)	8.4(+7)	Negligible
Min	2.2(-12)	1.4(+10)	2.3(+8)	6.0(+9)		5.9(-16)	3.8(+6)	6.6(+4)	1.6(+6)	
50 ±Y										
Max	6.6(-11)	4.1(+11)	7.2(+9)	1.9(+11)		1.8(-14)	1.1(+8)	1.9(+6)	5.0(+7)	
Min	1.3(-12)	8.3(+9)	1.4(+8)	3.7(+9)		3.5(-16)	2.2(+6)	3.7(+4)	1.0(+6)	
25° ±Y										
Max	8.0(-11)	4.7(+11)	8.4(+9)	2.3(+11)		2.2(-14)	1.3(+8)	2.3(+6)	6.0(+7)	
Min	1.8(-12)	1.1(+10)	1.9(+8)	5.0(+9)		4.9(-16)	3.0(+6)	5.2(+4)	1.3(+6)	
50°±Y 45°+X										
Max	4.7(-11)	2.9(+11)	5.1(+9)	1.4(+11)		1.3(-14)	7.8(+7)	1.4(+6)	3.7(+7)	
Min	1.6(-12)	9.4(+9)	1.7(+8)	4.4(+9)		4.3(-16)	2.5(+6)	4.6(+4)	1.2(+6)	
50° -X										
Max	1.7(-10)	1.3(+12)	1.8(+10)	4.8(+11)		4.6(-14)	3.5(+8)	4.9(+6)	1.3(+8)	
Min	1.5(-12)	9.4(+9)	1.6(+8)	4.4(+9)		4.1(-16)	2.5(+6)	4.4(+4)	1.2(+6)	
50° +X										
Max	4.6(-11)	2.8(+11)	4.8(+9)	1.3(+11)		1.2(-14)	7.6(+7)	1.3(+6)	3.5(+7)	
Min	1.7(-12)	1.0(+10)	1.7(+8)	4.7(+9)		4.6(-16)	2.7(+6)	4.7(+4)	1.3(+6)	

* $(-10) = 10^{-10}$
** All polar molecules.
(1) BBRC Report (Reference 12).
(2) Schwinghamer Memo (Reference 14).

APPLICABLE CRITERIA

- Number Column Density(NCD) less than 10^{12} polar molecules/cm^2.
- Return Flux less than 10^{12} molecules/cm^2/second.

Table V. Outgassing Induced Environment Rate Comparison
Predictions for Spacelab SMTP Configuration

Predicted Parameters / Line-of-sight/ Temperature	Outgassing Rate[1] = 1.0×10^{-8} g/cm^2/second at 100°C					Outgassing Rate[2] = 2.7×10^{-12} g/cm^2/second at 100°C				
	MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux (Max) (mol/cm^2/second)			MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux (Max) (mol/cm^2/second)		
			700 km	435 km	200 km			700 km	435 km	200 km
0° +Z										
Max	1.4(-10)*	8.6(+11)	1.5(+10)	4.0(+11)	Negligible	3.8(-14)	2.3(+8)	4.1(+6)	1.1(+8)	Negligible
Min	7.7(-12)	4.9(+10)	8.4(+8)	2.2(+10)		2.1(-15)	1.3(+7)	2.3(+5)	6.0(+6)	
50° ±Y										
Max	8.1(-11)	5.0(+11)	8.4(+9)	2.3(+11)		2.2(-14)	1.4(+8)	2.3(+6)	6.6(+7)	
Min	4.2(-12)	2.6(+10)	4.4(+8)	1.2(+10)		1.1(-15)	7.0(+6)	1.2(+5)	3.2(+6)	
25° ±Y										
Max	9.3(-11)	5.8(+11)	9.6(+9)	2.6(+11)		2.5(-14)	1.6(+8)	2.6(+6)	7.2(+7)	
Min	5.7(-12)	3.6(+10)	6.0(+8)	1.6(+10)		1.5(-15)	9.7(+6)	1.6(+5)	4.4(+6)	
50° ±Y 45°+X										
Max	7.0(-11)	4.4(+11)	7.2(+9)	2.0(+11)		1.9(-14)	1.2(+8)	1.9(+6)	5.3(+7)	
Min	5.8(-12)	3.6(+10)	6.0(+8)	1.7(+10)		1.6(-15)	9.7(+6)	1.6(+5)	4.6(+6)	
50° -X										
Max	2.6(-10)	1.6(+12)	2.8(+10)	7.2(+11)		7.0(-14)	4.3(+8)	7.2(+6)	1.9(+8)	
Min	5.4(-12)	3.4(+10)	5.8(+8)	1.6(+10)		1.5(-15)	9.2(+6)	1.6(+5)	4.2(+6)	
50° +X										
Max	8.2(-11)	5.1(+11)	8.4(+9)	2.3(+11)		2.2(-14)	1.4(+8)	2.3(+6)	6.6(+7)	
Min	6.8(-12)	4.3(+10)	7.2(+8)	2.0(+10)		1.8(-15)	1.2(+7)	1.9(+5)	5.3(+6)	

* (-10) = 10^{-10}
** All polar molecules.
(1) BBRC Report (Reference 12).
(2) Schwinghamer Memo (Reference 14).

APPLICABLE CRITERIA
- Number Column Density (NCD) less than 10^{12} polar molecules/cm^2.
- Return Flux less than 10^{12} molecules/cm^2/second.

Table VI. Outgassing Induced Environment Rate Comparison Predictions for Spacelab FP Configuration

Predicted Parameters / Line-of-Sight & Temperature	Outgassing Rate(1) = 1.0×10^{-8} g/cm^2/second at 100°C					Outgassing Rate(2) = 2.7×10^{-12} g/cm^2/second at 100°C				
	MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux (Max) (mol/cm^2/second)			MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux (Max) (mol/cm^2/second)		
			700 km	435 km	200 km			700 km	435 km	200 km
0° +Z					Negligible					Negligible
Max	2.9(-11)*	1.8(+11)	3.1(+9)	8.4(+10)	↓	7.8(-15)	4.9(+7)	8.4(+5)	2.3(+7)	↓
Min	1.3(-11)	7.8(+10)	1.3(+9)	3.6(+10)	↓	3.5(-15)	2.1(+7)	3.5(+5)	9.6(+6)	↓
50° ±Y					↓					↓
Max	2.0(-11)	1.3(+11)	2.2(+9)	5.8(+10)	↓	5.4(-15)	3.5(+7)	5.8(+5)	1.6(+7)	↓
Min	1.3(-11)	8.5(+10)	1.4(+9)	3.7(+10)	↓	3.5(-15)	2.3(+7)	3.7(+5)	1.0(+7)	↓
25° ±Y					↓					↓
Max	2.5(-11)	1.6(+11)	2.7(+9)	7.2(+10)	↓	6.8(-15)	4.3(+7)	7.2(+5)	1.9(+7)	↓
Min	1.3(-11)	8.5(+10)	1.4(+9)	3.7(+10)	↓	3.5(-15)	2.3(+7)	3.7(+5)	1.0(+7)	↓
50 ±Y 45° +X					↓					↓
Max	2.6(-11)	1.7(+11)	2.8(+9)	7.2(+10)	↓	7.0(-15)	4.6(+7)	7.2(+5)	1.9(+7)	↓
Min	1.1(-11)	7.2(+10)	1.2(+9)	3.2(+10)	↓	3.0(-15)	1.9(+7)	3.2(+5)	8.4(+6)	↓
50° -X					↓					↓
Max	3.7(-11)	2.4(+11)	4.0(+9)	1.1(+11)	↓	1.0(-14)	6.5(+7)	1.1(+6)	2.9(+7)	↓
Min	1.0(-11)	6.5(+10)	1.1(+9)	2.9(+10)	↓	2.7(-15)	1.8(+7)	2.9(+5)	7.8(+6)	↓
50° +X					↓					↓
Max	3.7(-11)	2.4(+11)	4.0(+9)	1.1(+11)	↓	1.0(-14)	6.5(+7)	1.1(+6)	2.9(+7)	↓
Min	1.0(-11)	6.5(+10)	1.1(+9)	2.9(+10)	↓	2.7(-15)	1.8(+7)	2.9(+5)	7.8(+6)	↓

* (-11) = 10^{-11}
**All polar molecules.
(1) BBRC Report (Reference 12).
(2) Schwinghamer Memo (Reference 14).

APPLICABLE CRITERIA

- Number Column Density (NCD) less than 10^{12} polar molecules/cm^2.
- Return Flux less than 10^{12} molecules/cm^2/second.

In order to quantitatively compare the model predictions with the criteria for deposition on optical surfaces which states that no more than 1% absorption from the IR through UV by condensibles is allowable (Reference 1), the worst case situation was investigated for the LMOP configuration. The analysis was limited to this configuration since it is expected to represent the highest induced environment level of the three modeled Spacelab configurations, and it is the only configuration to have the updated thermal profile data incorporated. Figure 6 presents parametrically the outgassing deposition predictions for the LMOP configuration as a function of sensitive optical surface temperature and Spacelab orbital altitude. The deposition levels presented are based upon the following assumptions:

1) the optical surface is continuously exposed for a seven day mission;

2) the optical surface has a geometric acceptance angle of 28 degrees (0.19 steradians);

3) the Spacelab orbit is such that all surfaces are continuously at their maximum temperatures;

4) the optical surface is continuously oriented to receive the maximum return flux;

5) the density of the ambient atmosphere used to determine the return flux is the medium density for the altitudes investigated; and

6) at altitudes down to 250 km the collisions of the outgassed molecules with the ambient atmosphere do not significantly attenuate the predicted molecular densities.

The predictions in Figure 6 are for the baseline outgassing rate of 1×10^{-5} g/cm^2/second at 100^{o}C. It is apparent that the 1% absorption criteria is exceeded

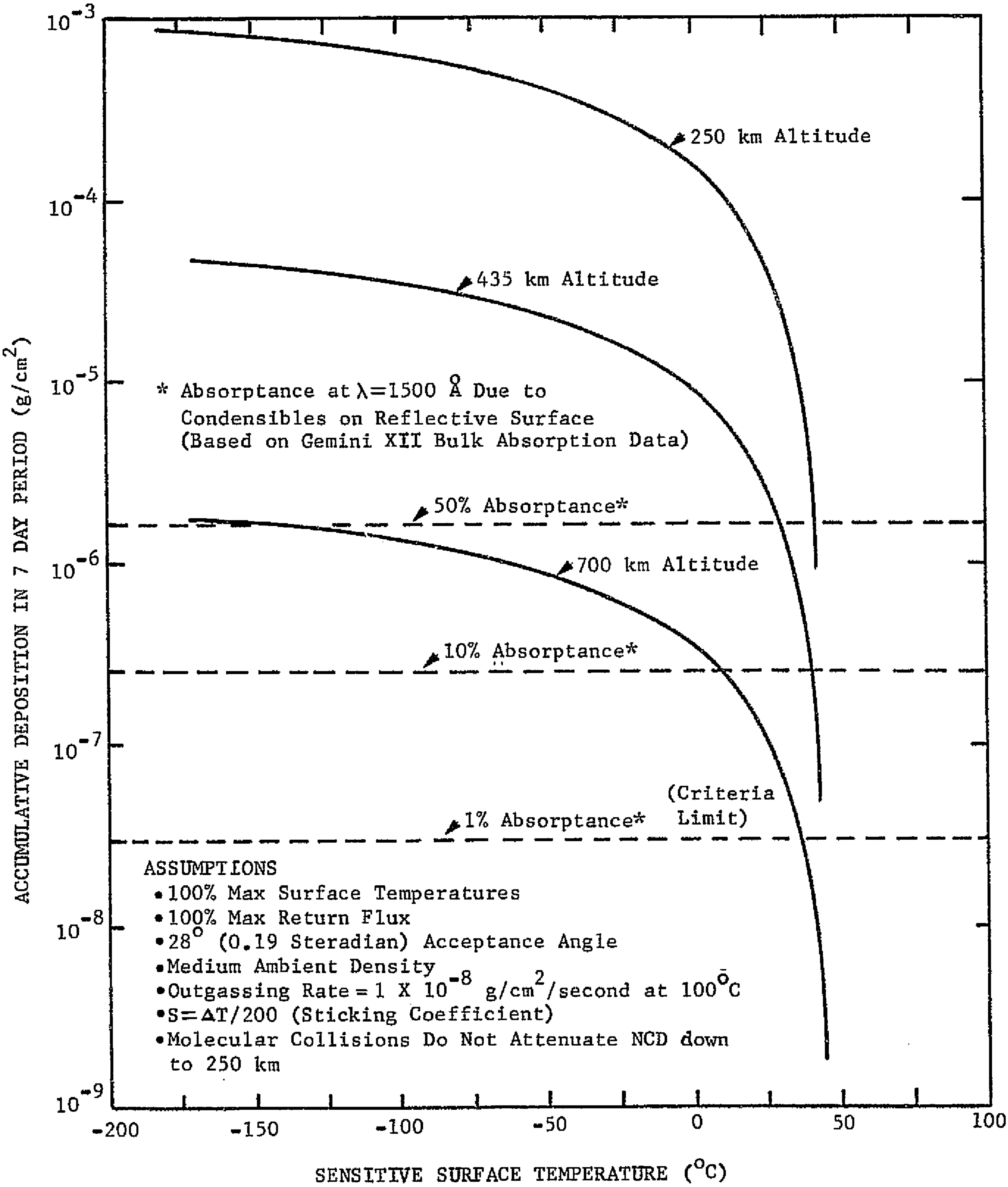


Figure 6. Outgassing Deposition for the LMOP Spacelab Configuration for a Seven Day Mission as a Function of Sensitive Surface Temperature

for an optical surface detecting at an ultraviolet wavelength of 1500Å at all altitudes and optical surface temperatures below approximately 38°C. This is based upon bulk absorption data acquired during the Gemini XII program for typical spacecraft outgassing deposits. Even by assuming the ATM canister type S13G outgassing rate of 2.7×10^{-12} g/cm^2/second at 100°C (which decreases the deposition predictions in Figure 6 by a factor of 3.7×10^{3}), the 1% absorption criteria will be exceeded at the lower altitudes. It can be seen through rationing that in order to meet the 1% absorption criteria the Spacelab vehicle must demonstrate an effective outgassing rate less than approximately 1×10^{-13} g/cm^2/second at 100°C based upon the stated assumptions. This is an extremely low rate which may prove to be very difficult to achieve.

Several options do exist which would reduce the contaminant impacts from outgassing deposition on optical surfaces. The Spacelab carrier could meet the intent of the 1% absorption criteria through materials selection control to the 1×10^{-13} g/cm^2/second outgassing rate at 100°C as determined in the preceding paragraph or by limiting the location and area of coverage of nonmetallic materials used on Spacelab which might involve the total elimination of nonmetallic thermal control material altogether. If this proves impractical, the susceptible scientific instruments may be required to make certain adjustments in order to meet the intent of the criteria. These would include one or a combination of several of the following:

1) provide protective devices such as sensitive surface covers and aperture doors along with proper operational timelining to insure minimum surface exposure to contamination;

2) design the instruments to provide the smallest practical geometric acceptance angles for the sensitive surfaces;

3) thermally control sensitive surfaces to temperatures which will preclude condensation of impinging outgassing molecules (ideally greater than $40^{\circ}C$);

4) establish flight operations for the scientific instruments that avoid the maximum return flux situations (i.e. orbit at the highest practical altitude, avoid surface exposure during hot portions of an orbit, and establish observation requirements that avoid the ambient drag vector being perpendicular to the sensitive optical surface); and

5) on an individual basis, each affected scientific instrument Principal Investigator should reevaluate the need for contamination controls as restrictive as the 1% absorption criteria.

To put this into perspective, it is necessary to establish what level of outgassing that is required in order to satisfy all of the contamination control criteria and to compare this level with the outgassing rates of nonmetallic materials qualified under current materials screening criteria such as 50M02442 (Reference 7) and SP-R-0022A (Reference 8). The applicable requirements extracted from these criteria are summarized below:

1) 50M02442 Requirements (Paragraph 3.2)

   (a) Weight loss rate during temperature cycling from $25^{\circ}C$ to $100^{\circ}C$ shall not exceed $0.2\%/cm^2$/hour when heated at a rate of $2^{\circ}C$/minute.

   (b) Steady-state weight loss rate at $100^{\circ}C$ shall not exceed $0.04\%/cm^2$/hour. Steady-state is defined as that point where the rate has been constant for 8 hours.

   (c) Desorption of surface adsorbed atmospheric gases or other contaminants shall be included in the rates.

2) SP-R-0022A Requirements (Paragraph 7.4)

(a) The materials shall have a VCM content of $<0.1\%$ by weight. The total weight loss of material shall not exceed 1.0% by weight.

(b) This is for a 24 hour test period for samples at $125^{\circ}C$.

Data acquired from vacuum testing of S13G used on Skylab indicated that a typical application of S13G would have a thickness on the order of 6 mils and a mass-to-area ratio of 0.052 g/cm^2. Using this data in conjunction with the materials selection criteria equates to a maximum allowable mass loss rate for S13G of approximately 6×10^{-9} g/cm^2/second at $100^{\circ}C$ for both 50M02442 and SP-R-0022A. Under the assumptions of this analysis, this level in conjunction with anticipated decreases in the predicted induced environment for the SMTP and FP configurations (when complete thermal profile data is available) should be sufficiently low enough to bring the predicted NCD's within the criteria of 10^{12} polar molecules/cm^2 for all Spacelab lines-of-sight and configurations. However, to meet the return flux criteria of 10^{12} molecules/cm^2/second under all circumstances an effective Spacelab thermal control surface outgassing rate of approximately 1×10^{-9} g/cm^2/second is necessary. This is somewhat more restrictive than the levels implied by materials screening criteria, but could be achievable once recommended testing is completed for the major Spacelab nonmetallic materials (especially S13G) and, based upon the resulting outgassing rate data, analysis is completed to determine the locations and maximum allowable area of coverage by the S13G to satisfy the return flux criteria. As presented earlier in this section, by far, the most restrictive criteria applicable to outgassing, is the 1% maximum allowable absorption due to condensibles. An effective outgassing rate for the Spacelab thermal control surfaces less than 1×10^{-13} g/cm^2/second at $100^{\circ}C$ is necessary to meet this criteria under worst

case conditions. Extensive control measures instituted by not only the Spacelab but also by susceptible scientific instruments may be necessary to meet the intent of this criteria. Table VII presents a summary of all of the outgassing rate information discussed in this section and how it applies to the data being presented in this report.

In addition to attenuating incoming electromagnetic radiation data for the scientific instruments, deposited outgassants will also discolor and degrade the performance of Spacelab and scientific instrument white thermal control surfaces. This is especially true for deposits which are exposed to ultraviolet radiation which tends to cause photopolymerization of the deposits and result in an increase in solar absorptivity of the thermal control surfaces in conjunction with varying degrees of discoloration from yellow to brown. This phenomena was observed on Skylab and will be accumulative from mission to mission. Even if the Spacelab and scientific instrument thermal control systems can tolerate the resulting solar absorptivity increases, the discoloration may be undesirable from an aesthetic point of view. This may dictate extensive ground refurbishment requirements in order to maintain a first launch appearance for the Spacelab carrier.

The worst case levels of degradation can be semi-quantitatively determined through the use of predicted deposition levels in Figure 6 and from data obtained during the Skylab Program. Assuming a 2π steradian field-of-view for the Spacelab and scientific instrument thermal control surfaces facing in a +Z direction the worst case deposition level for a seven day mission would be approximately 6×10^{-4} g/cm^2 at 250 km based upon the LMOP maximum temperature thermal profile. Data acquired from S13G witness samples flown on the Skylab vehicle in conjunction with Skylab contamination computer modeling indicates that this level of deposition under ultraviolet radiation could increase the solar absorptivity of the Spacelab/scientific instrument S13G

Table VII. Summary of Spacelab Thermal Control Surface Outgassing Rate Rationale

Outgassing Rate* (g/cm^2/second at $100^{\circ}C$)		Comments/Rationale
$1.0x10^{-8}$	Input Data	Rate used as baseline for S13G in this study. Reference 12 pre-Skylab testing by Ball Brothers Research Company.
$2.7x10^{-12}$	Input Data	Rate supplied by MSFC Materials and Processes Laboratory (Reference 14) for highly cured and controlled S13G used on the Skylab ATM canister.
$6.0x10^{-9}$	Criteria Dependent Data	Empirically determined maximum allowable outgassing rate for nominal application of S13G per materials screening criteria 50M02442 (Reference 7) and SP-R-0022A (Reference 8) equates to the maximum allowable rate to meet NCD criteria.
$1.0x10^{-9}$	Criteria Dependent Data	Maximum allowable outgassing rate for S13G assuming 100% Spacelab coverage to meet return flux criteria.
$1.0x10^{-13}$		Approximate maximum allowable outgassing rate for S13G assuming 100%. Spacelab coverage to meet the 1% absorption criteria for a 7 day mission assuming continuous worst case return flux impingement/deposition to a 0.19 steradian surface detecting at 1500Å.

* The outgassing rates are given for presentation purposes at $100^{\circ}C$ which is reflective of the majority of materials testing maximum temperature limit. The contamination model uses this rate as initial input data and calculates corresponding rates as a function of surface temperatures during any one mission.

surfaces as much as 0.19 from an initial value of 0.18 to 0.37. The impact of this level of degradation is currently not known. Indications are that fairly tight tolerances exist for the allowable degradation of the pallet surfaces to insure proper structural/thermal balances during reentry. However, these tolerances are not yet available and should be supplied by ESRO such that an accurate assessment might be made of the potential degradation. The current contamination control criteria makes no reference to allowable levels of thermal control surface degradation, therefore, the logical source for such information would be ESRO.

Table VIII through X present the induced environment predictions for the three modeled Spacelab configurations for the early on orbit emission of absorbed and adsorbed light gases, liquids, and volatiles (referred to in this report as materials offgassing). Contained in these tables is a comparison of the predictions based upon the Ball Brothers Research Company (BBRC) S13G test data (Reference 12) and the MSFC Materials and Processes Laboratory ATM canister S13G data (Reference 14). The data presented in these tables is formatted consistent with that of the previous outgassing predictions. Analytically, offgassing is treated as a non-steady state source reaching a maximum rate upon initial exposure to space vacuum and decaying rapidly with time. The BBRC baseline model offgassing rate for S13G of 2.5×10^{-7} g/cm^2/second at $100^{o}C$ was established for the 10 hour point in the decay curve. This point was chosen to be representative of that elapsed time period on orbit when operations of instruments susceptible to this type of contamination might be expected to commence. Unfortunately, the available data for the ATM canister S13G does not indicate an offgassing rate at the 10 hour point. Therefore, for the comparative predictions contained in Tables VIII through X, the initial offgassing rate of 2.5×10^{-10} g/cm^2/second at $100^{o}C$ was used for the ATM S13G paint.

Table VIII. Offgassing Induced Environment Rate Comparison Predictions for Spacelab LMOP Configuration

Predicted Parameters / Line-of-sight Temperature	Offgassing Rate[1] = 2.5×10^{-7} g/cm^2/second at 100°C at 10 Hour Point					Offgassing rate[2] = 2.5×10^{-10} g/cm^2/second at 100°C at Initial Point				
	MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux(Max) (mol/cm^2/second)			MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux(Max) (mol/cm^2/second)		
			700 km	435 km	200 km			700 km	435 km	200 km
0° +Z										
Max	1.1(-9)*	3.8(+13)	2.3(+10)	6.3(+11)	3.3(+13)	1.1(-12)	3.8(+10)	2.3(+7)	6.3(+8)	3.3(+10)
Min	2.3(-11)	7.7(+11)	4.6(+8)	1.3(+10)	6.9(+11)	2.3(-14)	7.7(+8)	4.6(+5)	1.3(+7)	6.9(+8)
50° ±Y										
Max	7.0(-10)	2.3(+13)	1.4(+10)	4.0(+11)	2.2(+13)	7.0(-13)	2.3(+10)	1.4(+7)	4.0(+8)	2.2(+10)
Min	1.4(-11)	4.7(+11)	2.7(+8)	7.9(+9)	4.0(+11)	1.4(-14)	4.7(+8)	2.7(+5)	7.9(+6)	4.0(+8)
25° ±Y										
Max	8.5(-10)	2.8(+13)	1.7(+10)	3.6(+11)	2.5(+13)	8.5(-13)	2.8(+10)	1.7(+7)	3.6(+8)	2.5(+10)
Min	1.9(-11)	6.2(+11)	3.6(+8)	1.0(+10)	5.6(+11)	1.9(-14)	6.2(+8)	3.6(+5)	1.0(+7)	5.6(+8)
50° ±Y 45° +X										
Max	5.2(-10)	1.6(+13)	1.0(+10)	2.8(+11)	1.5(+13)	5.2(-13)	1.6(+10)	1.0(+7)	2.8(+8)	1.5(+10)
Min	1.7(-11)	5.7(+11)	3.3(+8)	9.6(+9)	4.9(+11)	1.7(-14)	5.7(+8)	3.3(+5)	9.6(+6)	4.9(+8)
50° -X										
Max	1.8(-9)	6.1(+13)	3.6(+10)	1.0(+12)	5.3(+13)	1.8(-12)	6.1(+10)	3.6(+7)	1.0(+9)	5.3(+10)
Min	1.6(-11)	5.2(+11)	3.3(+8)	9.6(+9)	4.9(+11)	1.6(-14)	5.2(+8)	3.3(+5)	9.6(+6)	4.9(+8)
50° +X										
Max	4.7(-10)	1.6(+13)	9.2(+9)	2.8(+11)	1.4(+13)	4.7(-13)	1.6(+10)	9.2(+6)	2.8(+8)	1.4(+10)
Min	1.8(-11)	6.2(+11)	3.6(+8)	1.0(+10)	5.3(+11)	1.8(-14)	6.2(+8)	3.6(+5)	1.0(+7)	5.3(+8)

* (-9) = 10^{-9}
** All polar molecules.
(1) BBRC Report (Reference 12).
(2) Schwinghamer Memo (Reference 14).

APPLICABLE CRITERIA

- Number Column Density(NCD) less than 10^{12} polar molecules/cm^2.
- Return Flux less than 10^{12} molecules/cm^2/second.

Table IX. Offgassing Induced Environment Rate Comparison Predictions for Spacelab SMTP Configuration

Predicted Parameters / Line-of-Sight Temperature	Offgassing Rate(1) = 2.5×10^{-7} g/cm^2/second at 100°C at 10 Hour Point					Offgassing Rate(2) = 2.5×10^{-10} g/cm^2/second at 100°C at Initial Point				
	MCD	NCD**	Return Flux (Max) (mol/cm^2/second)			MCD	NCD**	Return Flux (Max) (mol/cm^2/second)		
	(g/cm^2)	(mol/cm^2)	700 km	435 km	200 km	(g/cm^2)	(mol/cm^2)	700 km	435 km	200 km
0° +Z Max	1.5(-9)*	4.9(+13)	3.0(+10)	8.2(+11)	4.3(+13)	1.5(-12)	4.9(+10)	3.0(+7)	8.2(+8)	4.3(+10)
Min	8.0(-11)	2.7(+12)	1.6(+9)	4.6(+10)	2.5(+12)	8.0(-14)	2.7(+9)	1.6(+6)	4.6(+7)	2.5(+9)
50° ±Y Max	8.5(-10)	2.8(+13)	1.7(+10)	4.6(+11)	2.5(+13)	8.5(-13)	2.8(+10)	1.7(+7)	4.6(+8)	2.5(+10)
Min	4.4(-11)	1.5(+12)	8.9(+8)	2.5(+10)	1.3(+12)	4.4(-14)	1.5(+9)	8.9(+5)	2.5(+7)	1.3(+9)
25° ±Y Max	9.8(-10)	3.2(+13)	1.9(+10)	5.6(+11)	2.9(+13)	9.8(-13)	3.2(+10)	1.9(+7)	5.6(+8)	2.9(+10)
Min	6.1(-11)	2.0(+12)	1.2(+9)	3.3(+10)	1.8(+12)	6.1(-14)	2.0(+9)	1.2(+6)	3.3(+7)	1.8(+9)
50° ±Y 45° +X Max	7.4(-10)	2.4(+13)	1.4(+10)	4.3(+11)	2.2(+13)	7.4(-13)	2.4(+10)	1.4(+7)	4.3(+8)	2.2(+10)
Min	6.2(-11)	2.0(+12)	1.2(+9)	3.6(+10)	1.8(+12)	6.2(-14)	2.0(+9)	1.2(+6)	3.6(+7)	1.8(+9)
50° -X Max	2.7(-9)	9.0(+13)	5.3(+10)	1.5(+12)	7.9(+13)	2.7(-12)	9.0(+10)	5.3(+7)	1.5(+9)	7.9(+10)
Min	5.7(-11)	1.9(+12)	1.1(+9)	3.2(+10)	1.7(+12)	5.7(-14)	1.9(+9)	1.1(+6)	3.2(+7)	1.7(+9)
50° +X Max	8.7(-10)	2.9(+13)	1.1(+10)	4.9(+11)	2.6(+13)	8.7(-13)	2.9(+10)	1.1(+7)	4.9(+8)	2.6(+10)
Min	7.2(-11)	2.4(+12)	1.4(+9)	4.0(+10)	2.1(+12)	7.2(-14)	2.4(+9)	1.4(+6)	4.0(+7)	2.1(+9)

* (-9) = 10^{-9}
** All polar molecules.
(1) BBRC Report (Reference 12).
(2) Schwinghamer Memo (Reference 14).

APPLICABLE CRITERIA
- Number Column Density (NCD) less than 10^{12} polar molecules/cm^2.
- Return Flux less than 10^{12} molecules/cm^2/second.

Table X. Offgassing Induced Environment Rate Comparison Predictions for Spacelab FP Configuration

Predicted Parameters / Line-of-Sight Temperature	Offgassing Rate[1] = 2.5×10^{-7} g/cm^2/second at 100°C at 10 Hour Point					Offgassing Rate[2] = 2.5×10^{-10} g/cm^2/second at 100°C at Initial Point				
	MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux (Max) (mol/cm^2/second)			MCD (g/cm^2)	NCD** (mol/cm^2)	Return Flux (Max) (mol/cm^2/second)		
			700 km	435 km	200 km			700 km	435 km	200 km
0° +Z										
Max	3.1(-10)*	1.0(+13)	6.3(+9)	1.8(+11)	9.2(+12)	3.1(-13)	1.0(+10)	6.3(+6)	1.8(+8)	9.2(+9)
Min	1.4(-10)	4.4(+12)	2.6(+9)	7.6(+10)	4.0(+12)	1.4(-13)	4.4(+9)	2.6(+6)	7.6(+7)	4.0(+9)
50° ±Y										
Max	2.3(-10)	7.6(+12)	4.6(+9)	1.3(+11)	6.9(+12)	2.3(-13)	7.6(+9)	4.6(+6)	1.3(+8)	6.9(+9)
Min	1.4(-10)	4.4(+12)	2.6(+9)	7.6(+10)	4.0(+12)	1.4(-13)	4.4(+9)	2.6(+6)	7.6(+7)	4.0(+9)
25° ±Y										
Max	2.7(-10)	8.9(+12)	5.3(+9)	1.6(+11)	7.9(+12)	2.7(-13)	8.9(+9)	5.3(+6)	1.6(+8)	7.9(+9)
Min	1.4(-10)	4.4(+12)	2.6(+9)	7.6(+10)	4.0(+12)	1.4(-13)	4.4(+9)	2.6(+6)	7.6(+7)	4.0(+9)
50° ±Y 45° +X										
Max	2.9(-10)	9.6(+12)	5.6(+9)	1.7(+11)	8.6(+12)	2.9(-13)	9.6(+9)	5.6(+6)	1.7(+8)	8.6(+9)
Min	1.2(-10)	4.0(+12)	2.4(+9)	6.9(+10)	3.6(+12)	1.2(-13)	4.0(+9)	2.4(+6)	6.9(+7)	3.6(+9)
50° -X										
Max	3.8(-10)	1.3(+13)	7.6(+9)	2.2(+11)	1.1(+13)	3.8(-13)	1.3(+10)	7.6(+6)	2.2(+8)	1.1(+10)
Min	1.0(-10)	3.3(+12)	2.0(+9)	5.9(+10)	3.0(+12)	1.0(-13)	3.3(+9)	2.0(+6)	5.9(+7)	3.0(+9)
50° +X										
Max	3.8(-10)	1.3(+13)	7.6(+9)	2.2(+11)	1.1(+13)	3.8(-13)	1.3(+10)	7.6(+6)	2.2(+8)	1.1(+10)
Min	1.0(-10)	3.3(+12)	2.0(+9)	5.9(+10)	3.0(+12)	1.0(-13)	3.3(+9)	2.0(+6)	5.9(+7)	3.0(+9)

* (-10) = 10^{-10}

** All polar molecules.

(1) BBRC Report (Reference 12).

(2) Schwinghamer Memo (Reference 14).

APPLICABLE CRITERIA

- Number Column Density (NCD) less than 10^{12} polar molecules/cm^2.
- Return Flux less than 10^{12} molecules/cm^2/second.

Assuming that essentially all of the offgassing species are polar (infrared active) in nature, the predicted NCDs for the baseline S13G offgassing rate exceed the criteria of 10^{12} polar molecules/cm^2 for all lines-of-sight and most of the temperature extremes of the three Spacelab configurations. The same is basically true for the return flux criteria of 10^{12} molecules/cm^2/second at altitudes below approximately 400 km. Offgassed molecules having an assumed diameter of 3Å (as opposed to outgassed molecules with a diameter of 30Å) will demonstrate a return flux capability at 200 km due to their longer mean free path. For those instruments that are susceptible to these high NCDs and/or those that have exposed sensitive cryogenic surfaces which can condense impinging offgassing species, proper operational timelining can avoid this initial high mass loss period and will preclude any significant degradation due to offgassing.

Here again, as with outgassing, the model predictions for the ATM type S13G initial offgassing rate depicted in Tables VIII through X fall well within the limits of the NCD and return flux criteria for all altitudes, temperature extremes, and Spacelab configurations.

It should be realized when analyzing any Spacelab mission that not only must the Spacelab vehicle meet the established criteria, but also that the combined Spacelab/Shuttle Orbiter induced environment must be held within tolerable limits. To determine the resulting combined induced environment predictions, the existing Shuttle Orbiter Contamination Model is used in conjunction with its Spacelab counterpart. Therefore, for completeness and quick reference, the Shuttle Orbiter outgassing and offgassing induced environment predictions have been included in Appendix E of this report in a format consistent with the Spacelab predictions.

b) Spacelab Cabin Atmosphere Leakage Update - Although the source parameters of Spacelab cabin atmosphere leakage from the pressurized modules have not been modified over those depicted in the previous Spacelab contamination analysis report (Reference 5), additional induced environment predictions were determined for the eight new lines-of-sight of the SMTP configuration. These are presented in Table XI along with the previous predictions for the LMOP configuration. Included in Table XI are the total mass and number column densities along with the number column densities of the individual constituents. Also depicted are the molecular return flux levels at 700, 435, and 200 km altitudes. The predicted polar NCD (CO_2 and H_2O) for both configurations meets the 10^{12} polar molecules/cm^2 criteria. However, the return flux at 200 km slightly exceeds 10^{12} molecules/cm^2/second in all cases. This may present a problem to cryogenic instruments in the 4 to 20^oK range which must view near the orbital plane for extended periods of time. The return flux impacts resulting from Spacelab leakage can be minimized through the proper choice of vehicle attitudes which avoid the ambient drag vector being perpendicular to the sensitive surfaces. Here again, for completeness, the induced environment predictions for the Shuttle Orbiter atmospheric leakage are included in Appendix E.

c) Return Flux Refinement for Surfaces with Large Acceptance Angles - As stated in subsection 2.1.3.1-a, the predictions contained in the preceding tables are based upon a geometric acceptance angle of 0.19 steradians. This was chosen to be representative of a typical optical telescope assembly (2 meters long by 1 meter diameter) mounted at the center point of the various Spacelab pallet configurations. The quantity of material capable of impinging upon a sensitive surface through return flux or line-of-sight transport is a direct function of its geometric acceptance angle. Therefore, for surfaces exhibiting acceptance angles near 0.19 steradians, impingement predictions can be determined by the product of the ratio of the acceptance angles and the 0.19

Table XI. Leakage Induced Environment Predictions for the Modeled Spacelab Configurations***

Line-of-Sight & Configuration (Predicted Parameters)	MCD (g/cm^2)	NCD** Total (mol/cm^2)	NCD O_2 (mol/cm^2)	NCD N_2 (mol/cm^2)	NCD** CO_2 (mol/cm^2)	NCD** H_2O (mol/cm^2)	Return Flux(Max) ($mol/cm^2/second$) 700 km	435 km	200 km
0^o +Z LMOP	1.1(-10)*	2.2(+12)	4.8(+11)	1.7(+12)	1.5(+10)	4.0(+10)	1.4(+9)	4.1(+10)	2.2(+12)
SMTP	1.2(-10)	2.4(+12)	5.2(+11)	1.8(+12)	1.6(+10)	4.4(+10)	1.5(+9)	4.5(+10)	2.4(+12)
50^o $\pm$Y LMOP	1.0(-10)	2.1(+12)	4.3(+11)	1.6(+12)	1.4(+10)	3.7(+10)	1.3(+9)	3.7(+10)	2.0(+12)
SMTP	8.5(-11)	1.7(+12)	3.7(+11)	1.3(+12)	1.2(+10)	3.1(+10)	1.1(+9)	3.2(+10)	1.7(+12)
25^o $\pm$Y LMOP	1.1(-10)	2.2(+12)	4.8(+11)	1.7(+12)	1.5(+10)	4.0(+10)	1.4(+9)	4.1(+10)	2.2(+12)
SMTP	9.3(-11)	1.9(+12)	4.0(+11)	1.5(+12)	1.3(+10)	3.4(+10)	1.2(+9)	3.5(+10)	1.8(+12)
50^o $\pm$Y, 45^o +X LMOP	6.8(-11)	1.4(+12)	2.9(+11)	1.1(+12)	9.3(+9)	2.5(+10)	9.0(+8)	2.5(+10)	1.3(+12)
SMTP	6.1(-11)	1.3(+12)	2.6(+11)	9.7(+11)	8.3(+9)	2.2(+10)	8.0(+8)	2.3(+10)	1.2(+12)
50^o -X LMOP	2.0(-10)	4.2(+12)	8.7(+11)	3.2(+12)	2.7(+10)	7.4(+10)	2.6(+9)	7.5(+10)	3.9(+12)
SMTP	2.1(-10)	4.3(+12)	9.1(+11)	3.3(+12)	2.9(+10)	7.7(+10)	2.8(+9)	7.8(+10)	4.1(+12)
50^o +X LMOP	5.3(-11)	1.1(+12)	2.3(+11)	8.4(+11)	7.3(+9)	1.9(+10)	7.0(+8)	2.0(+10)	1.0(+12)
SMTP	6.1(-11)	1.3(+12)	2.6(+11)	9.7(+11)	8.4(+9)	2.2(+10)	8.0(+8)	2.3(+10)	1.2(+12)

* (-10) = 10^{-10}
** Polar Constituents
*** Leak Rate = 1.35 kg/day

APPLICABLE CRITERIA

- Number Column Density(NCD) less than 10^{12} polar molecules/cm^2.
- Return Flux less than 10^{12} molecules/cm^2/second.

steradian surface predictions. This would also possibly be true for surfaces with much larger acceptance angles if the contaminant number column density remained constant throughout the field-of-view of the surface. However, for surfaces such as the Spacelab viewing windows and thermal control surfaces which have essentially 2π steradian acceptance angles, it becomes apparent that this assumption will no longer hold true. Several physical and geometric relationships must be taken into account as well as the fact that the NCD is by no means a constant over 2π steradians for all sources. To assess the resultant contaminant impact to these types of surfaces, an analytical approach published by Robertson (Reference 15) is currently being utilized. In this approach, the contaminant flux on a 2π steradian surface perpendicular to the ambient drag vector is determined by:

$$I_{\perp} = 2/3\ N_A V_A\ \sigma_A N_C$$

where

$I_{\perp}$ = Impingement with drag vector perpendicular to surface in molecules/cm^2/second,

N_A = Ambient molecular density in molecules/cm^3,

V_A = Ambient velocity (spacecraft velocity) in cm/second,

σ_A = Collision cross section in cm^2/molecule,

N_C = Contaminant column density in molecules/cm^2.

Impingement upon a 2π steradian surface that is parallel to the ambient drag vector is determined to be:

$$I_{/\!/} = (0.3471)\ I_{\perp}$$

Realizing that the column densities vary appreciably over a 2π steradian field-of-view, the value for N_C in the Robertson approach is taken to be the average column density in the 2π volume within the plane of the ambient

drag vector. This is an approximation and care must be used in particular situations such as with point sources where the contaminant density can vary drastically along a line-of-sight and between lines-of-sight. It is apparent from this discussion that this is not the final approach for determining return flux to large field-of-view surfaces. However, for the current level of development of the Spacelab contamination model, it is felt to be applicable in yielding representative return flux predictions for these surfaces. This methodology has been utilized throughout the contaminant impact studies conducted during this contract period.

d) Sticking Coefficient Approach Rationale - The ratio of mass depositing on a surface to the total mass impinging is referred to as the sticking coefficient or condensation coefficient. This ratio is strongly dependent on temperature for a given contaminant and the surface of interest.

For the majority of contaminant sources (e.g. offgassing, cabin leakage, and evaporator) the current contamination model allows a unity sticking coefficient for a substance if the surface temperature is below the boiling point of the contaminant. At the same time, the contaminant is allowed to desorb as a function of its vapor pressure. Where vapor pressure data is available, the mass depositing is expressed as:

Net mass depositing = (mass adsorption - mass desorption)

or

$$D\ (g/cm^2) = (F(I-J)\cdot S(I-J)\cdot \Delta t) - (5.83\times 10^{-2}\,\gamma\, P_v (M/T)^{\frac{1}{2}}\cdot \Delta t)$$

where $F(I-J)$ = Flux on surface I from source J,

$S(I-J)$ = Sticking coefficient (unity or zero),

T = Temperature ^{o}K of surface I,

t = Time interval $F(I-J)$ and T are constant,

γ = Desorption coefficient ($0 \leq \gamma \leq 1$),

P_v = Vapor pressure at temperature of surface I,

M = Molecular weight.

The above relationship yields the net gain of mass per unit area from a contaminant source J and is always equal to or greater than zero. It also accounts for desorption rate changes as the temperature of surface I varies with time.

Outgassing contaminant sources are characteristically a combination of molecular species for which the molecular sizes, relative abundance of each specie, and total quantity outgassed are a strong function of temperature. Vapor pressure data for each deposition outgassant specie is generally unavailable or limited at best. For polymeric contaminant sources, the problem is further complicated by the fact that the deposited material can undergo chemical reactions or can be photopolymerized in the presence of ultraviolet radiation. The result is that the vapor pressure or the desorption energy of the parent source material does not apply to the deposited outgassed species. In general, the deposited material has a larger desorption energy (and therefore greater adhesive qualities) than the parent material.

Because of the unavailability of vapor pressure or desorption energy data for this type of deposit, the current model approach is to determine the sticking coefficient as a function of the temperature difference between the source and the receiving surface. Once the deposit is determined, it is not allowed to desorb. This assumption is based on the fact the sticking coefficient is obtained from materials testing such as the Volatile Condensible Material (VCM) measurements which are long term in nature (References 16, 17, and 18) and the likelihood is high that chemical reaction or photopolymerization will occur at the surface. Both of these phenomena tend to fix the deposit. This approach was used in the Skylab modeling with apparent success.

The present sticking coefficient has the form:

$$S = \frac{TJ-TI}{K} \quad [TI < TJ]$$

and $S = 0 \quad [TI \geq TJ]$

where TJ = Source J temperature in ^{o}C or ^{o}K,

TI = Surface I temperature in ^{o}C or ^{o}K,

K = A constant which is a characteristic of the material.

For the majority of nonmetallic contaminant sources, the factor K has been determined to be near 200.

The sticking coefficient as described above has been found to relate the percent VCM to the percent total weight loss from materials testing with the source at 125^{o}C and the receiving surface at 25^{o}C. It also has been found to correlate with measurements made during RTV 560 outgassing tests of the Shuttle Orbiter Thermal Protection System (TPS) tile configuration at MSFC (Reference 19). To be specific, with the TPS panel at 65.5^{o}C and a quartz crystal microbalance (QCM) detector at 25^{o}C, the QCM measured a deposition rate of $3x10^{-11}$ g/cm^2/second. For this case, TJ-TI is 40.5^{o}C. With the TPS panel at 65.5^{o}C and the same QCM at -35^{o}C, the QCM read $8x10^{-11}$ g/cm^2/second. For this case, the TJ-TI is 100.5^{o}C. The ratio of the QCM measurement at the two temperatures is 2.7, while the ratio of the two temperature differences (i.e. the ratio of the sticking coefficients) is 2.5. This indicates good correlation between the change in the current model sticking coefficient with respect to temperature changes of the receiving surface and actual test data of a major Shuttle Orbiter outgassing surface.

In a continuing effort to upgrade the method of determining sticking coefficients and subsequent desorption of the deposited material in the model, several alternative approaches have been investigated. These are briefly described in the following paragraphs with a current assessment of their applicability to contamination modeling.

During the Viking materials testing program at Martin Marietta Aerospace, Denver Division, several unique outgassing measurements were made. Of these tests, one in particular has application to determining sticking coefficients. From Residual Gas Analysis (RGA) data, it was observed that the sum of the mass peaks above mass 44 ratioed to the total sum of the mass peaks present in the spectrum yielded the sticking coefficient for a collecting surface at 25°C. This was supplemented with additional VCM type testing which verified the observed results within 10%.

An important consideration to this approach is that the test chamber be cleaned and baked out prior to testing so that residual outgassants from a previous test do not add to the background mass readings and lead to erroneous results. The possible application of this approach for several specific nonmetallic materials for Spacelab is being investigated. Additional testing would be required to evaluate major materials of interest over the range of temperatures anticipated for Spacelab. It should be pointed out that this approach is similar to the temperature dependent relationship currently in the model. That is to say as the source temperatures are elevated, greater fractions of the total mass spectrum occur beyond mass 44 thus increasing the sticking coefficient.

Ideally the activation energy of the deposited contaminant should be known over an anticipated temperature range. This data coupled with VCM data at various source and receiver temperatures would allow a detailed assessment of the deposit. Also required is the potential environmental effects such as ultraviolet radiation and possibly electrons and protons on the desorption energy of the deposit.

Initial data may be obtained for one major Shuttle Orbiter source from the continued testing of the TPS panel at MSFC. As this test data becomes available, it will be assessed and implemented into the model.

The Braunauer, Emmett, Teller (BET) approach (Reference 20) was investigated for multilayer adsorption on critical surfaces. The key to the BET solution is the assumption that the activation energy of desorption after the first molecular monolayer deposits is that of the heat of liquefaction of the bulk deposit. In other words, the desorption-condensation properties of the second and higher molecular layers of deposit are assumed to be the same as those of the surface of the bulk liquid (deposit).

It is presently felt that the BET approach has limited value to the situation of nonmetallic materials outgassing. Essentially one would require knowledge of the characteristics of each outgassed molecular species which includes the heat of liquefaction, the saturation vapor pressure, and the chemical reactions occurring at the surface (the BET approach does not account for these reactions). In addition, the BET approach breaks down in the region from zero pressure to P/P_o = 0.05 to 0.1, where P equals the incident pressure and P_o is the saturation vapor pressure.

Based upon the investigations to date, it is concluded that testing of the major Spacelab/Shuttle Orbiter nonmetallic materials is the most direct way to determine sticking coefficients and the subsequent desorption of deposited contaminants.

In addressing second surface source phenomena, the model does include those secondary sources deemed most significant to the contaminant environment such as the reflections of the VCS and evaporator vent effluents off of the Shuttle Orbiter wings. The model currently handles only first surface considerations for outgassing (i.e. once an outgassing specie impinges upon a surface its additional impact of desorbing and affecting a second surface or contributing to the contaminant cloud thickness has been previously evaluated to be a second order effect and determined to have a minimal impact to the final predictions). However, since concern has been

expressed on this approach for outgassing and other sources, current reevaluation is underway to determine what modifications if necessary might be required to include this secondary source impact. As stated previously, the item which limits the ability to accurately model this phenomena is the lack of sufficient desorption data on typical spacecraft nonmetallic material outgassing deposits.

2.1.3.2 Shuttle Orbiter Model Sources Updates - The major updates and modifications made to the Shuttle Orbiter model contamination sources which influenced the Spacelab contamination impact analyses of this study included 1) evaporator vent baseline flowrate adjustment; 2) expansion of the 900 lb Reaction Control System (RCS) engine analysis; and 3) expansion of the Orbital Maneuvering System (OMS) engine analysis. These efforts were conducted concurrently under separate contract to JSC (Reference 6) with the Spacelab modeling and assessment studies under contract to MSFC and are reflected where applicable throughout this report. Although none of these are Spacelab emitted contaminant sources, their ultimate impacts to Spacelab unique hardware and Payloads must be included for complete contamination assessment. In addition, Spacelab and Payload mission objectives and requirements dictate the usage requirements for most of above Shuttle Orbiter contaminant sources. Therefore, for completeness, these modifications are discussed herein and the resulting updated induced environment predictions along with those for the other major Shuttle Orbiter sources are included in Appendix E. These are presented in a format consistent with the previously presented Spacelab predictions for ease of interpretation.

a) Evaporator Update - Although extensive analysis has been conducted into alternative locations for the Shuttle Orbiter evaporator vents, the baseline vent location remains at $X_o = 1392$, $Y_o = \pm 113$, and $Z_o = 323$ pending further analysis and testing planned at JSC. The flowrate of this vent system has been increased from 11 lb H_2O/hour (5.5 lb/hour/vent) to 30 lb H_2O/hour (15 lb/hour/vent) and has been incorporated into the Shuttle Orbiter Contamination Model. No adjustments were made to the evaporator flowfield relationships,

so the net result was to essentially triple the previous model predictions for molecular column densities and return flux to the Spacelab and Payloads.

b) <u>900 lb RCS Engine Update</u> - The Shuttle Orbiter contamination model was expanded to include those 900 lb RCS thrusters deemed most significant and representative of the 38 total currently planned for the Shuttle Orbiter. These included the 20 engines located aft of the Shuttle Orbiter OMS pods firing in the $\pm Z$ and $\pm Y$ directions. Engine plume flowfield descriptions were modeled using an approach developed by Simons (Reference 21) for determining the mass flux at any point in the exhaust plume as a function of distance from the engine exit plane and angle off the plume centerline where

$$\dot{m} = \frac{1400}{r^2}\left[\cos\left(\frac{\pi}{2}\cdot\frac{\theta}{\theta_i}\right)\right]^{10} \qquad 0^\circ \leq \theta \leq 60^\circ$$

$$\dot{m} = \frac{61.32}{r^2}\left[e^{-0.128\,\alpha\,(\theta-60)}\right] \qquad 60^\circ \leq \theta \leq 180^\circ$$

where; $\dot{m}$ = Mass flux rate in g/cm^2/second,

r = Distance from exit plane of engine nozzle in cm,

θ = Angle from engine centerline in degrees,

θ_i = 125°,

α = Constant between 0.5 and 1.0.

This approach is consistent with those of engine evaluators who are concerned with these flowfields during engine design and development phases. As these engines are designed and tested, any adjustments and subsequent impacts to the flowfields should be reassessed.

The primary use of these engines is for major pitch, yaw, and roll maneuvers and translation maneuvers during deployment and retrieval of satellite systems. Therefore, although the predicted NCD values presented in Appendix E are extremely high for certain engines and lines-of-sight, sensitive instruments will most likely not be operating during these maneuvers. Consequently, the major impact of these thrusters on the Spacelab and its Payloads will be from the return flux of exhaust effluents through interaction with the ambient atmosphere.

c) Orbital Maneuvering System Engine Update - The Shuttle Orbiter contamination model has been expanded to include the assessment capabilities for both forward and retro thrust OMS engine maneuvers for their impacts to surfaces of Spacelab and scientific instruments in the Shuttle Orbiter payload bay. This approach should be considered as preliminary since very little OMS data is available and the computer model calculation routines have not been completely established. However, the resulting contamination predictions are felt to be representative for the maneuvers analyzed.

The OMS engine system is primarily used for major orbital changes, orbital insertion ıd deorbit initiation maneuvers. This system consi of two 6000 lb thrust hypergolic MMH/N_2O_4 engines ..unted on the aft thrust structure of the Shuttle Orbiter, firing in essentially a +X (aft) direction. For each second of engine operation, approximately 21.6 lbs of fuel per thruster will be consumed. Geometrically, no direct line-of-sight exists between the OMS engines and Spacelab or scientific instrument surfaces located within the Shuttle Orbiter payload bay envelope. Consequently, the major transport mechanism of engine effluent species to surfaces in the payload bay will be the return flux of exhausted molecules resulting from their interaction with the molecules in the ambient atmosphere.

To determine the return flux levels to the payload bay surfaces, a mathematical plume description was developed that is compatible with the format of the Spacelab Contamination Computer Model. The required flowfield relationships used in the modeling were derived from preliminary analysis of the OMS engines based upon the assumption that these engines are similar to the Skylab CSM R4-D 100 lb thrust MMH/N_2O_4 engines when scaled to the 6000 lb thrust level. When detailed engine parameters such as chamber pressures and injector designs become available, these flowfield descriptions will require updating.

The exhaust plume of the OMS engines was modeled using an approach developed by Simons (Reference 21) which was modified to establish a closed form analytical representation for angles from 0 to 140 degrees off of the engine centerline. This angular range encompasses the major portion of the mass in the OMS engine flowfield. However, beyond 140 degrees, the experimental data of Chirivella and Simon (Reference 22) indicates that the mass flux may approach a constant value becoming independent of θ. Based upon this information, this phenomena was incorporated into the present study by modifying the Simons approach to predict a constant mass flux in the plume for angles between 140 and 180 degrees. Using this modified approach, the following relationships were developed to determine the mass flux from the OMS engines:

$$\dot{m} = \frac{1.39 \times 10^4}{r^2} \left[\cos\left(\frac{\pi}{2} \cdot \frac{\theta}{170^\circ}\right)\right]^{10} \qquad 0^\circ \leq \theta \leq 30^\circ$$

$$\dot{m} = \frac{9.55 \times 10^3}{r^2} \left[e^{-0.14\,\alpha\,(\theta - 30^\circ)}\right] \qquad 30^\circ \leq \theta \leq 140^\circ$$

$$\dot{m} = \frac{9.55 \times 10^3}{r^2} \left[e^{-15.4\,\alpha}\right] \qquad 140^\circ \leq \theta \leq 180^\circ$$

where

$\dot{m}$ = Mass flux rate in g/cm^2/seconds,

r = Distance from the exit plane of the engine in centimeters,

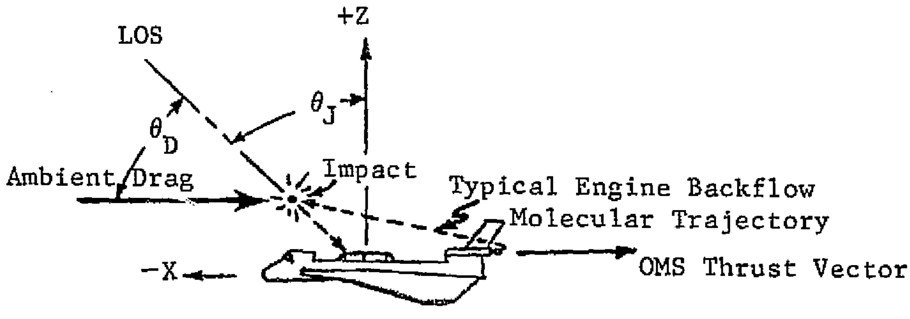
θ = Angle off of the engine centerline in degrees,

α = Constant between 0.5 and 1.0.

Using these relationships, the mass flux rate from each OMS engine can be determined at any point in the flowfield as a function of r and θ. The nominal velocity of the exhaust effluents has been determined from gas dynamic relationships to be approximately 3694 meters/seconds assuming a γ (C_p / C_v) of 1.2.

Several, more highly sophisticated methods exist to determine engine flowfield descriptions including the McDonnell Douglas/AFRPL CONTAM computer program for plume contamination effects predictions. Most of these, including CONTAM, are relatively expensive to utilize and have not as yet been proven or verified through test or flight data. It seems to be the general concensus of cognizant people in the field of engine plume technology that the approach by Simons is as cost effective and practical an approach to plume definition predictions as is currently available.

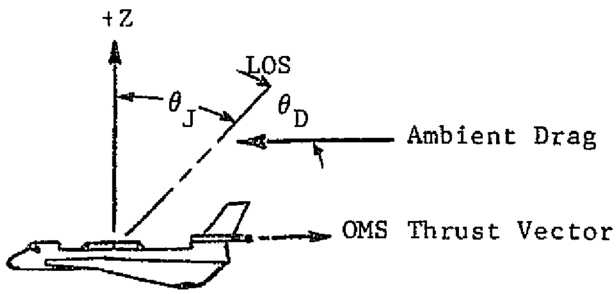
During the orbital insertion OMS firings and ensuing forward thrust maneuvers, only the backflow portion of the engine flowfields is involved and able to reach a surface in the payload bay through interaction with the ambient environment. This phenomena is illustrated in the following schematic.



The amount of backflow effluents capable of flowing in the -X direction will be limited by the mean free path of the emitted molecules in the ambient flux. Therefore, the engine flux flowing in the -X direction is attenuated by $e^{-R/\lambda}$, where R = distance to the point of interest in the backflow field in inches and λ = mean free path of the exhausted molecules as a function of velocity and ambient molecular density. From the point of impact of an exhausted molecule with the ambient, the exhausted molecule is assumed to be reflected in the direction of the ambient drag vector with a random or Lambertian distribution. The return flux to a 2π steradian surface in the payload bay in the (X,Y) plane is determined by calculating the molecular column densities in the forward quarter sphere (between the +Z and the -X axes). The ambient molecular density utilized to determine the return flux for these forward thrust maneuver predictions is the average density between the burn initiation altitude and termination altitude. A $\pi/2$ steradian cone centered around the line-of-sight for this forward quarter sphere is assumed for the payload bay surfaces. For this assumed field-of-view, the return flux is determined for the line-of-sight having the average molecular density in the forward quarter sphere. The resulting return flux is then attenuated by the cosine of the angle that the modeled line-of-sight makes with the surface normal (θ_J) and the cosine of the average angle the drag vector makes with the line-of-sight (θ_D).

Several Spacelab/Shuttle Orbiter missions require retro firing maneuvers of the OMS engines to lower orbital altitudes during mission operations, and all require retro-thrusts for deorbit initiation. If these are conducted with the payload bay doors open, a potential exists for severe degradation to exposed Spacelab/scientific instrument surfaces in the payload bay. These maneuvers require the engines to fire into the ambient drag vector creating a near maximum return flux situation. Engine effluents will be swept across the Spacelab and scientific instrument surfaces depositing in varying degrees depending upon surface shadowing and temperature considerations.

Return flux to a surface in the payload bay in the (X, Y) plane with a 2π steradian field-of-view is determined by calculation of the molecular column densities in the vehicle aft quarter sphere (between the +Z and the +X axes) again using the Simons approach for plume definition assuming the ambient density remains constant for each burn. The resulting return flux which is assumed to be confined to a $\pi/2$ steradian cone centered around the line-of-sight is then attenuated by the cosine of the angle (θ_J) that the modeled line-of-sight makes with the surface normal and the cosine of the average angle (θ_D) the drag vector makes with the lines-of-sight in the aft quarter sphere. The schematic below illustrates these relationships.



These methods were used to determine the OMS engine effluent impingement upon a surface in the (X, Y) plane in the payload bay representative of the Spacelab +Z facing windows and thermal control surfaces as a function of orbital altitude. This is illustrated in Figure 7 for both the forward and retro thrust maneuvers for a two engine operation. Total impingement can be determined for any maneuver using Figure 7 by knowing the burn time required and the altitudes at burn initiation and termination.

Once the engine effluent impingement has been determined for the OMS burns (either from retro or forward thrust), the amount that sticks to a surface is calculated based upon sticking coefficient data derived from MMH/N_2O_4 engine testing conducted at Lewis Research Center and from Skylab QCM flight data. Lewis data indicated that 0.2% (S=0.002) of impinging engine effluents initially stuck to test surfaces at approximately $2^{\circ}C$. The test employed ultraviolet radiation which essentially fixed the deposit, therefore, the long term sticking coefficient for the MMH/N_2O_4 engine effluents under ultraviolet radiation is 0.002 for temperatures in the vicinity of $2^{\circ}C$. At cryogenic temperatures $S \simeq 1.0$. Skylab QCM flight data of MMH/N_2O_4 engine deposits not exposed to ultraviolet radiation demonstrated a similar 0.002 sticking coefficient initially at approximately $10^{\circ}C$. However, this deposition sublimated exponentially with time reaching a value of 1/e (37%) of the initial deposit in approximately 72 hours and decaying to final value of approximately 20% of the initial deposit. In as much as the probability of solar ultraviolet radiation of OMS engine deposits is quite high for any one mission, a sticking coefficient of 0.002 is used for these deposits.

The Lewis Research Center engine contamination data currently being used was derived from testing of a small 5 lb thrust MMH/N_2O_4 engine operating in a pulse mode. It is realized that the larger engines such as the OMS

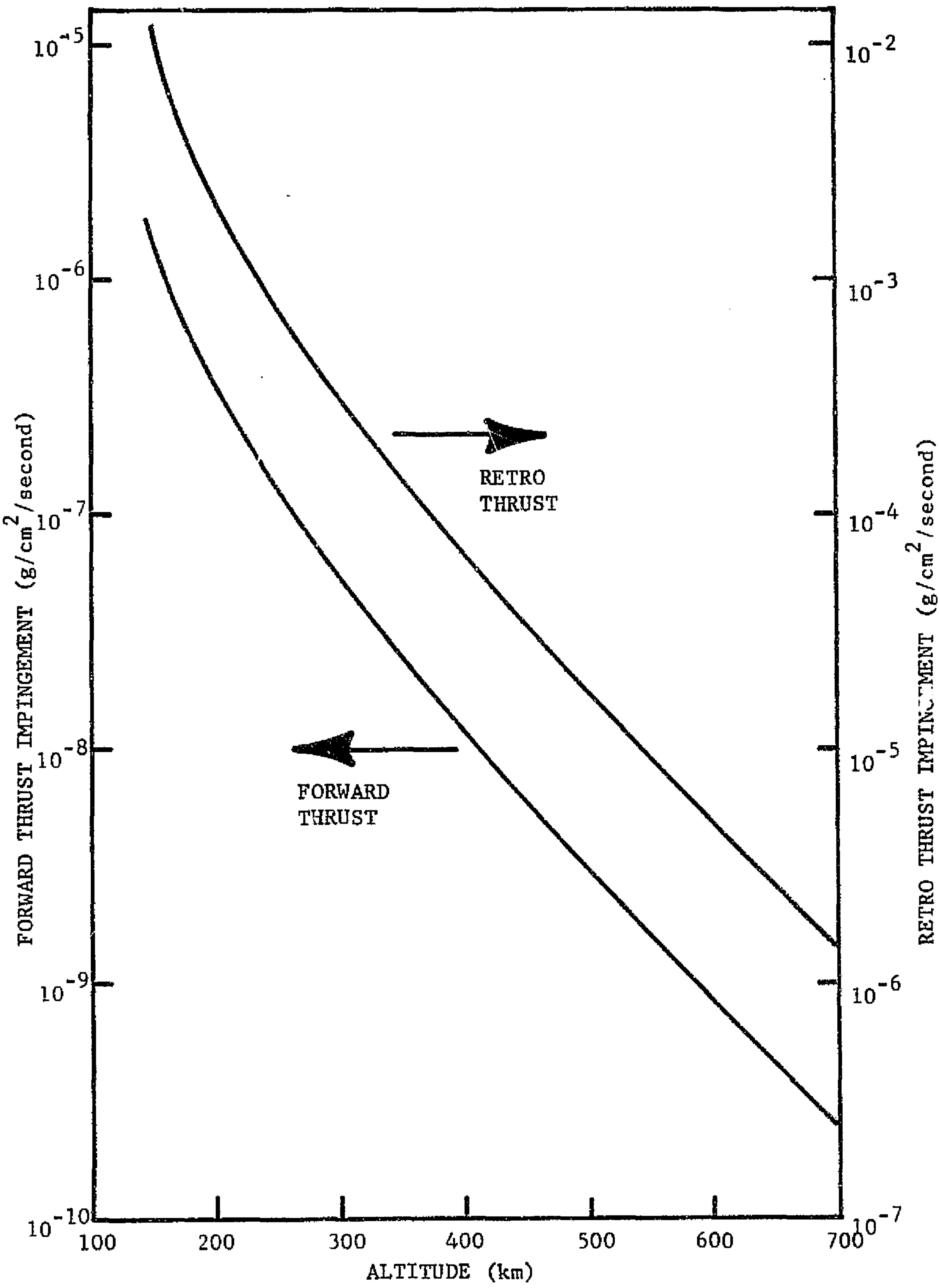


Figure 7. OMS Effluent Impingement on Spacelab Surfaces as a Function of Orbital Altitude

will tend to combust more efficiently when operating in a non-pulse steady state mode and might potentially be less contaminating than the smaller engines tested. However, due to the size and mass flow of the OMS engines and the current unknowns in the engine design, the potential of severely contaminating vehicle surfaces must be recognized. The analyses contained herein are based upon the Lewis test data which most likely worst cases the OMS engine effluent deposition relationships.

2.1.4 Mission Profile Data Bank - Precise knowledge of certain characteristics of each Spacelab mission is necessary to accurately assess the effects of contamination on each critical operational surface or optic. This basic information must include all orbital characteristics and mission timelines as well as the critical physical characteristics of all Payload instruments and of the Spacelab/Shuttle Orbiter vehicle. To provide ready accessibility to all of this basic data, a Mission Profile Data Bank (MPDB) has been created to operate in conjunction with the Spacelab Configuration Contamination Model (SCCM) computer program. The rationale and structure of the MPDB is described below.

To date, the Mission Profile Data Bank (MPDB) includes available mission and payload data for Missions 16, 10, and 19a as based upon preliminary releases of Payload description documents (References 2 and 3) and the Integrated Mission Analysis Planning (IMAP) documents for each mission. Mission 12 is being added to the MPDB as additional data is acquired.

2.1.4.1 MPDB Rationale and Operating Philosophy - The basic operating philosophy of the MPDB is to retain the greatest amount of flexibility to incorporate last minute changes in mission characteristics and/or objectives while utilizing to the greatest extent possible, all known Spacelab mission and Payload characteristics.

Preliminary review of the Spacelab Payload descriptions indicates that a minimum of several hundred missions have been identified to date. Although many of these are planned to be repetitive in nature, there will be variations in orbital parameters from mission to mission, combinations of Payloads, and length of

missions prior to the actual launch date. In addition, most of the Payloads have a wide variety of operating modes. Individual instruments in a Payload often operate independently of the rest of the instruments in that Payload. Consequently, the MPDB consists of four main input files whose purpose is to supply the necessary basic contamination data in an accessible, yet readily usable format. The input files, described in detail later, are as follows:

a) Mission Data File (MDF);

b) Spacelab Payload Data File (SPDF);

c) Spacelab Temperature Data File (STDF); and

d) Mission Profile Descriptive File (MPDF).

2.1.4.2 MPDB File Structure - The four MPDB files store the basic input data concerned with a particular mission. This data, including orbital parameters, instrument physical characteristics, vehicular temperatures and configurations, and mission timelines, is that required to accurately assess the effects of contamination upon the mission.

a) Mission Data File (MDF) - The MDF stores the orbital parameters for each mission. These parameters include the time period in which each Payload or instrument is operated, the orbital altitude and vehicle attitude as a function of mission time, and the beta and inclination angles for the mission. This file also tracks the total elapsed operating hours and the total number of missions for each of the Spacelab configurations to allow for corresponding adjustments in the contamination model.

   Figure 8 shows a sample section of an input format for Mission 10, as derived from the SSPD (Reference 2). This section of the format covers a time period between 61.5 and 83.0 hours after launch when the vehicle is operating at an altitude of 460 km. Three Payloads (SO-703, EO-703, and HE-11-S) are operating either simultaneously in various combinations.

GET-HRS TSTART	GET-HRS TSTOP	EQUIP CODE	VEHICLE ALTITUDE (KM)	VEHICLE ATTITUDE CODE	BETA ANGLE (DEG)	INCLIN-ATION (DEG)	TOTAL ELAPSED HOURS-VEHICLE
61.50	72.00	0420	460.0	7	TBD	57.0	419.0
61.50	72.00	0440	460.0	7	TBD	57.0	419.0
61.50	72.00	0460	460.0	7	TBD	57.0	419.0
61.50	72.00	0680	460.0	7	TBD	57.0	419.0
72.00	75.00	0420	460.0	5	TBD	57.0	491.0
72.00	75.00	0440	460.0	5	TBD	57.0	491.0
72.00	75.00	0460	460.0	5	TBD	57.0	491.0
72.00	75.00	0540	460.0	5	TBD	57.0	491.0
75.00	78.00	0420	460.0	10	TBD	57.0	494.0
75.00	78.00	0440	460.0	10	TBD	57.0	494.0
75.00	78.00	0460	460.0	10	TBD	57.0	494.0
78.00	82.00	0420	460.0	4	TBD	57.0	497.0
78.00	82.00	0440	460.0	4	TBD	57.0	497.0
78.00	82.00	0460	460.0	4	TBD	57.0	497.0
78.00	82.00	0540	460.0	4	TBD	57.0	497.0
82.00	83.00	0420	460.0	7	TBD	57.0	501.0
82.00	83.00	0440	460.0	7	TBD	57.0	501.0
82.00	83.00	0460	460.0	7	TBD	57.0	501.0
83.00	95.00	0420	460.0	5	TBD	57.0	513.0
83.00	95.00	0440	460.0	5	TBD	57.0	513.0
83.00	95.00	0460	460.0	5	TBD	57.0	513.0
83.00	95.00	0680	460.0	5	TBD	57.0	513.0

Figure 8. Contents and Format of the Spacelab Mission Data File (MDF)

The limits of each time period are defined by TSTART and TSTOP. Both the vehicle attitude and the instrument(s) in operation during this time period are specified by codes. The codes for typical vehicle attitudes are described in Table XII. The specific instrument codes will be described in the following paragraph.

Through the MDF, last-minute changes in mission profile can be incorporated in the Spacelab Configuration Contamination Model.

b) Spacelab Payload Data File (SPDF) - The SPDF is a permanent file containing all critical contamination data relating to Payloads to be flown on the Shuttle missions. Figure 9 shows a typical sample of the SPDF containing HE-11-S Payload information for Mission 10.

Data considered necessary for each mission are coded and developed as follows:

1) The code number (NEQP) for each instrument in a Payload whose performance is affected by contamination. Some instruments may be described by two or more code numbers depending upon the line-of-sight during operation.

2) The instrument inventory number (AEQP).

3) The Payload number (APYLD) corresponding to each instrument.

4) The physical location of the critical surface(s) of each instrument within the payload bay, referenced to the vehicle coordinate system (XCOR, YCOR, ZCOR).

5) The temperature of the critical surface(s) for each instrument (TPC).

6) The line-of-sight (LOS) of each instrument in relation to the Shuttle Orbiter vehicle.

Table XII. Definition of Spacelab/Shuttle Orbiter Operating Modes

Code	Mode	Description
1	Z-LV	Payload bay toward earth (non-inertial)
2	NOP	Payload bay toward north orbital pole (inertial)
3	VNOP	Payload bay toward vicinity of north orbital pole (inertial)
4	D	Payload bay pointed such that joint descending pass over the United States. Both EO-703 and HE-11-S operations are possible (inertial)
5	A	Same as D, except for ascending passes over the United States
6	S	Payload bay toward vicinity of sun such that joint SO-703/HE-11-S operations are possible (inertial)
7	SOP	Payload bay toward south orbital pole (inertial)
8	Solar	Payload bay toward sun (inertial)
9	TC	Payload bay pointed as required for Shuttle thermal conditioning
10	H	Intermediate Z body attitude, HE-11-S operations only

TPC = TEMPERATURE OF CRITICAL SURFACE (DEG K)

ZCOR = Z COORDINATE OF EXPERIMENT

LOS = LINE OF SIGHT NUMBER

YCOR = Y COORDINATE OF EXPERIMENT

XCOR = X COORDINATE OF EXPERIMENT

AANG = EXPERIMENT ACCEPTANCE ANGLE (DEG)

APYLD = PAYLOAD NUMBER

APNT = REQUIRED POINTING ACCURACY (DEG)

AEQP = EQUIPMENT INV. NUMBER

NEOP = EQUIPMENT CODE NUMBER

NEOP	AEQP	APYLD	XCOR	YCOR	ZCOR	TPC	LOS	AANG	APNT
0300	AS-150	AS-15-S	TBD	TBD	TBD	294.00	1	0.157	0.0835
0320	AS-151	AS-15-S	TBD	TBD	TBD	2.00	1	0.071	0.0835
0340	AS-152	AS-15-S	TBD	TBD	TBD	2.00	1	0.110	0.0835
0360	AS-153	AS-15-S	TBD	TBD	TBD	2.00	1	0.139	0.0835
0380	AS-154	AS-15-S	TBD	TBD	TBD	2.00	1	TBD	0.0835
0400	AS-155	AS-15-S	TBD	TBD	TBD	2.00	1	TBD	0.0835
0420	HE-221	HE-11-S	1160.00	0.	390.00	271.00	1	1.000	0.0167
0421	HE-221	HE-11-S	1160.00	0.	390.00	271.00	2	1.000	0.0167
0422	HE-221	HE-11-S	1160.00	0.	390.00	271.00	3	1.000	0.0167
0440	HE-222	HE-11-S	1160.00	0.	390.00	271.00	1	5.000	0.0167
0441	HE-222	HE-11-S	1160.00	0.	390.00	271.00	2	5.000	0.0167
0442	HE-222	HE-11-S	1160.00	0.	390.00	271.00	3	5.000	0.0167
0460	HE-223	HE-11-S	1160.00	0.	390.00	271.00	1	5.000	0.0167
0461	HE-223	HE-11-S	1160.00	0.	390.00	271.00	2	5.000	0.0167
0462	HE-223	HE-11-S	1160.00	0.	390.00	271.00	3	5.000	0.0167

Figure 9. Typical Contents and Format of the Spacelab Payload Data File (SPDF)

7) The acceptance angle (AANG) for each instrument.

8) The pointing accuracy (APNT) required for each instrument. (The most severe pointing requirement in any time period defines the VCS duty cycle.)

Therefore, preliminary data covering part or all of the instrument operations for each Spacelab Payload is available for inclusion into the SPDF. As the mission definitions become more fixed, the SPDF will be updated to include the new data.

c) Spacelab Temperature Data File (STDF) - The STDF will consist of a series of tables describing Spacelab surface temperature variation as a function of vehicle attitude. At present, the STDF consists of maximum and minimum temperatures for one Spacelab configuration (LMOP) and of preliminary data obtained from Reference 11 for the Spacelab SMTP and FP configurations. As data becomes available, the STDF will be updated.

d) Mission Profile Descriptive File (MPDF) - This file contains descriptive information about each mission and is used for annotating the output of the Spacelab Configuration Contamination Model. Although the MPDF has no computational interfaces, the use of this file will simplify the reading and interpretation of the output.

2.1.4.3 Spacelab Configuration Contamination Model Flow Logic - Figure 10 presents a logic flow diagram describing the relationship between the Mission Profile Data Bank and the Spacelab Configuration Contamination Model computer program. Both the Mission and Spacelab Payload Data Files are utilized during the initial stages of a Spacelab Configuration Contamination Model run. These two files combine to identify a complete mission timeline interrelating all Payload characteristics and operating times with orbital parameters and vehicle attitudes.

The Spacelab Temperature Data File and the Spacelab Source Parameters File combine with the existing Shuttle Orbiter data files to provide a complete model of the Spacelab/Shuttle Orbiter, describing contamination from all sources.

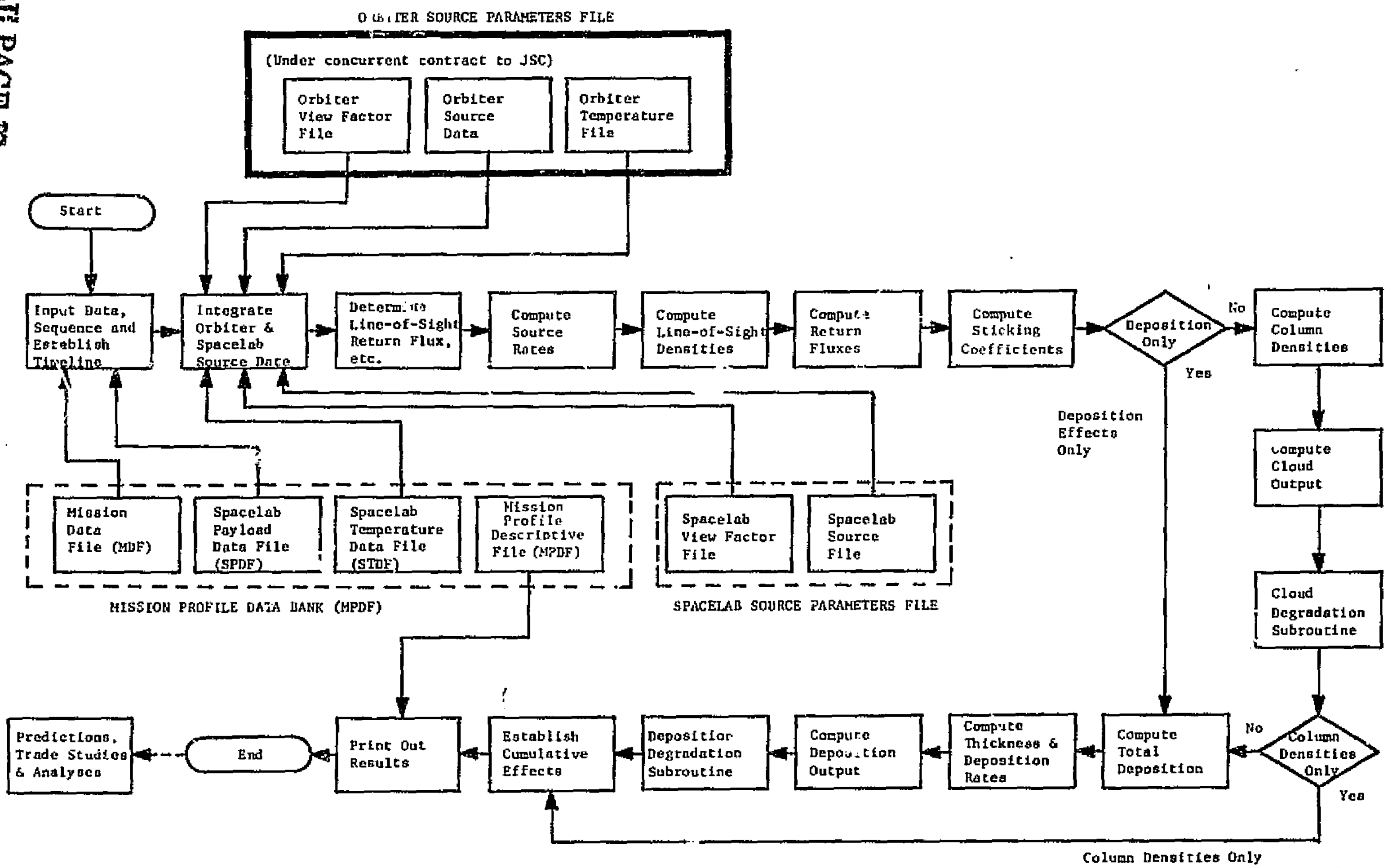


Figure 10. Preliminary Flow Diagram for Spacelab Configuration Contamination Model (SCCM) Computer Program

Finally, at the conclusion of a Spacelab Configuration Contamination Model analysis, the Mission Profile Descriptive File is used to annotate the output, as previously indicated.

2.2 Mission Compatibility/Trade Studies - This section identifies the mission compatibility studies conducted and presents the contamination impact trade study analyses performed during the contracted activity.

2.2.1 Mission Compatibility Studies - The mission compatibility studies performed to date are identified herein chronologically in order of conducted study activities. These studies were performed in accordance with scheduled activities and reflect the level of effort expended, the complexity of evaluation required, and the program format to be consistent with the scheduled periods of performance. The Spacelab missions evaluated to date include:

a) Mission 16 - High Energy Astrophysics;

b) Mission 10 - Pallet Flight Test Verification;

c) Mission 19a - Atmospheric, Magnetospheric, and Plasmas in Space (AMPS); and

d) Mission 12 - Life Sciences Shuttle Laboratory.

The detailed contamination assessment studies for these missions are contained in Appendices A through D respectively.

The compatibility analyses conducted were based upon the baseline contamination computer model as delineated in Section 2.1.1 and Reference 5 modified by all of the modeling and sources updates contained in Sections 2.1.2 and 2.1.3 with the single exception that the baseline Spacelab S13G thermal control coating outgassing rate of 1×10^{-8} g/cm^2/second at 100°C and offgassing rate of 2.5×10^{-7} g/cm^2/second at 100°C and the 10 hour point were utilized. Final modifications to these rates are pending the results of materials testing to be conducted by the MSFC Materials and Processes Laboratory on typical Spacelab nonmetallic

materials. Reference can be made to Tables IV through VI to determine modifications to the compatibility analyses predictions based upon the assumption that the highly controlled, extensively cured S13G as used on the Skylab ATM canister will be the selected Spacelab thermal control coating.

2.2.2 Trade Studies - Throughout the course of this contract period special trade studies were conducted into the contamination assessment of various Spacelab unique modifications and additional Spacelab source characteristics to determine their ultimate impacts to the Spacelab induced environment predictions. The two major areas that were investigated included the Spacelab Avionics Bay Vent system and the replacement of the aluminum honeycomb panels on the Spacelab pallet segments with graphite epoxy panels. These analyses are presented in detail in the following subsections.

a) Avionics Bay Vent Contamination Impact Analysis - This study was conducted in response to the Spacelab Action Item RID L/E-050A. The assumptions used in this analysis are stated below.

Flowrate: 3 lb/day continuous
Constituents: O_2 23% by weight
N_2 74% by weight
CO_2 1.0% by weight
H_2O 1.1% by weight
Trace 0.9% by weight
Location: Forward module cone section at $X_o = 681$
$Y_o = 0$, $Z_o = 57$
Vent direction: ~ 45 degrees off +Z axis toward -X axis in the X,Y plane
Plume Shape Function: Lambertian ($\cos\theta/r^2$)
Velocity: 412 m/second average
Temperature: 25°C
Spacelab Configuration: Short module/three pallet configuration

The Spacelab contamination computer model was used to determine the induced molecular mass and number colume densities and the return flux predictions for the Spacelab Avionics Bay Vent. The results are presented for three representative lines-of-sight for an optical instrument located at the center of the pallet configuration using a physical acceptance angle of 0.19 steradians. The lines-of-sight analyzed were: 1) parallel to the

Shuttle Orbiter +Z axis, 2) 50 degrees off the Orbiter +Z axis towards the ±Y axis, and 3) 50 degrees off the Shuttle Orbiter +Z axis towards the -X axis. These encompass the maximum viewing angles with respect to the Avionics Bay Vent as a contaminant source.

Line-of-Sight	MCD (g/cm^2)	Return Flux ($g/cm^2/sec$)	Return Flux ($mol/cm^2/sec$)		NCD	
		200 Km	435 Km	700 Km	Total (mol/cm^2)	Polar (mol/cm^2)
0^{o}	9.0(-11)*	8.0(-11) 1.8(+12)	1.5(-12) 3.3(+10)	5.4(-14) 1.2(+9)	2.0(+12)	4.2(+10)
50^{o} ±Y	4.3(-11)	3.9(-11) 8.6(+11)	7.3(-13) 1.6(+10)	2.6(-14) 5.7(+8)	9.5(+11)	2.0(+10)
50^{o} -X	1.8(-10)	1.6(-10) 3.2(+12)	3.1(-12) 6.8(+10)	1.1(-13) 2.4(+9)	4.0(+12)	8.5(+10)

* $(-11) = 10^{-11}$

The mass and number column densities resulting from the Spacelab Avionics Bay Vent are very close to being equal to those resulting from normal Spacelab module atmosphere leakage and an order of magnitude less than those resulting from leakage of the Shuttle Orbiter. As indicated above, there appears to be adequate margin between the predicted NCD and the related contamination control criteria of 10^{12} polar molecules/cm^2. The same is true for the return flux predictions at all altitudes except 200 km where the criteria of 10^{12} molecules/cm^2/second is slightly exceeded. This should, in general, present no problem to Spacelab and Spacelab payloads due to the small percentage of effluent material that will condense at temperatures other than cryogenic.

The Payloads that are susceptible to condensing the Avionics Bay Vent effluents are the cryogenic infrared telescopes. These payloads will be basically flown in a pallet only mode in which the pressurized module and

consequently the Avionics Bay Vent is not utilized. In addition, these Payloads will generally have physical or geometric acceptance angles less than the 28 degree modeled (0.19) physical field-of-view. For example, the 1.5 meter type infrared telescope has a physical acceptance angle of approximately 12 degrees. Therefore, return flux predictions for this instrument would decrease the values in the above table by a factor of 0.188 and in all cases would drop the predictions below 10^{12} molecules /cm^2/second. Because of the cryogenic nature of these payloads, they are constrained from exposure to even the flux of ambient molecules which can condense on the cold surfaces by utilizing proper vehicle orientations with respect to the velocity vector. This inherently decreases the potential of return flux even further of the contaminant molecules from the interactions with the ambient flux.

To worse case the number of potential particles produced by the condensation of the water vapor (humidity) content of the Avionics Bay Vent effluents into detectable particles, all of the vented humidity was assumed to condense into 10 micron radius ice particles. This results in a particle production rate of approximately 38 particles/second. Assuming a near spherical expansion of the resulting plume yields a cloud density of 6 particles/steradian/second or approximately one particle in a 4 arc minute half angle field-of-view each 7.26 orbits. The related contamination control criteria limits this rate to one particle/orbit. Therefore the worse case prediction falls well within the limits. Because much of this condensation will occur downstream of the vent exit plane, filtration of the vent system will not appreciably decrease the production of condensed particulates. However, to preclude the release of internally generated particles from the Avionics Bay (e.g., dust, lint, paint flakes, etc.), the vent system should include filtration in its design. Particles in the size range greater than or equal to 100 microns have the capicity to impact scientific data of the ultraviolet and infrared classes of scientific instruments. For this reason, filtration of the Avionics Bay Vent should be 100 microns or better. Filtration down to approximately

40 microns would be desirable to deter the emission of non-spherical particles having smaller dimensions in a given direction. Significant condensation of humidity on this filter screen system is not anticipated due to the relatively low flowrate of the vent.

b) <u>Graphite Epoxy Pallet Panel Contamination Impact Analysis</u> - This subsection presents the results of a contamination analysis conducted to determine the impact of replacing the aluminum honeycomb paneling on the Spacelab pallet structures with graphite epoxy carboform 69 panel material manufactured by Fothergill and Harvey. Materials screening test data derived as per ESRO specification PSS-09/QRM-02T (Reference 9) for this material indicates a total mass loss (TML) of 0.54% and a volatile condensible material (VCM) content of 0.02% during the 24 hour test period. Approximately 34 m^2 of this material will be used on each 3 meter pallet segment or approximately 58 kg per 3 meter pallet. This yields a configuration mass/area ratio of 1.7×10^{-1} g/cm^2 assuming uniform thickness.

Data derived from standard materials' screening technique (Reference 9) in predicting their contributions to the induced contaminant environment requires the utilization of several analytical assumptions to determine the necessary input parameters for those materials into the contamination computer model. This problem is inherent in using typical data from this type of materials testing. The contamination model depends upon several parameters which this type of testing does not normally yield. These include:

1) The mass loss rate of a material per unit surface area - Sample preparation of materials to be tested limits the ability to accurately determine the expected mass loss/area of a material for its anticipated use and area of application on a space vehicle.

2) The steady state bulk outgassing rate (OGR) data is buried within the TML and VCM data and is very difficult to accurately separate.

3) The exponential decay function of the offgassing rate (OFR) is also buried in the TML data and difficult to obtain.

4) The OFR and OGR as a function material temperature - Since the sample is held at a constant 125°C and the collector is held at 25°C only one data point on the mass loss rate as a function of temperature curve is obtained. In addition, only limited sticking coefficient data is obtained for a given material.

This is not to imply that the screening criteria serves no purpose in determining qualitatively whether or not a material is a high or low outgassing risk in spacecraft applications. What is apparent is that the value of this data for use in the contamination analysis and modeling of a spacecraft induced environment is somewhat limited. Since contamination control is a major reason for the screening criteria and the contamination model serves as an analytical tool in predicting the contamination environment, it follows then that for materials of significant area of coverage and/or at critical locations, testing should be expanded to obtain the desired data. As an example, testing has recently been conducted by MSFC on the Shuttle Orbiter Thermal Protection System (TPS) Reusable Surface Insulation (RSI) tiles (Reference 19). The outgassing characteristics of the RTV 560 bonding material used on these tiles is highly configuration dependent necessitating more detailed testing than the normal materials screening. Because of the abundant use of this material on the Shuttle Orbiter surfaces, the test was designed to supply the computer model with the required input data. With such data at hand for the major materials, the induced contaminant environment of a space vehicle such as the Spacelab due to outgassing and offgassing can accurately be established.

With the stated limitations, an analysis was conducted to determine the impact of using the graphite epoxy panels based on the available materials screening

test data. Assuming that the tested sample material was cut into perfect cubes yielded an effective mass to surface area ratio of one sixth of the configuration mass/area ratio or 2.83×10^{-2} g/cm^2. Since the VCM value is essentially the percentage of the total mass of a material at 125°C that condenses on a collector at 25°C, the total mass loss due to outgassing in 24 hours can be determined from:

$$S = \frac{T_s - T_c}{200} = \frac{125-25}{200} = 0.5 \text{ sticking coefficient}$$

and

$$S = \frac{\text{VCM\%}}{\text{TML outgassing \%}}$$

$$\therefore \quad \text{TML outgassing \%} = \frac{.02\%}{.5} = .04\%$$

Then the TML for offgassing (light volatiles) for this test would be 0.50% for 24 hours. Assuming that the bulk outgassing rate (OGR) is near constant throughout the test, this yields

$$OGR_{ave} = \frac{(\text{TML \%})\ (\text{effective mass/area})}{\text{Time}}$$

$$= \frac{(4 \times 10^{-4})(2.83 \times 10^{-2})}{(24)(60)(60)} = 1.30 \times 10^{-10} \text{ g/cm}^2\text{/second}$$

The offgassing rate of the graphite epoxy will characteristically decay rapidly from its initial value as a function of time of vacuum exposure. Similar materials tested by Scannapicco (Reference 23) demonstrated a near diffusion-limited process for mass loss as a function of time. This results in a near straight line offgassing decay curve with time which, for the epoxy and polyurethane materials tested, decreases approximately four orders of magnitude during the first 24 hours of testing. It is,

therefore, assumed that the graphite epoxy will offgas at a rate which peaks at initial exposure and decays as a straight line function to essentially zero after 24 hours. The area under the decay curve (i.e. OFR vs time) would be equal to the 0.50% total mass loss due to offgassing. Based upon these assumptions and the mass/area values previously discussed, the peak OFR = 6.58×10^{-9} g/cm^2/second and after 10 hours of vacuum exposure OFR = 3.83×10^{-9} g/cm^2/second. The 10 hour value is compatible with previous model predictions assuming that would be the point when Spacelab scientific instrument operations would presumably begin.

To determine the impacts of the above outgassing and offgassing rates on the Spacelab induced environment, the contamination computer model was run for the three previous modeled Spacelab configurations for one line-of-sight parallel to the Shuttle Orbiter +Z axis. The following results present the developed predictions. Contained therein are the predicted molecular number column densities along the modeled line-of-sight for the following possible options:

Configuration/ Max/Min Temp	Number Column Density (polar molecules/cm^2)					
	1) Baseline-** All S13G		2) Graphite Epoxy Pallet(s)		3) Graphite Epoxy with S13G** Coated Pallet(s)	
	OUT	OFF***	OUT	OFF***	OUT	OFF***
LMOP						
Max	1.45(+12)*	8.12(+13)	1.42(+12)	7.95(+13)	1.45(+12)	8.25(+13)
Min	2.64(+10)	1.49(+12)	1.53(+10)	8.57(+11)	2.66(+10)	1.51(+12)
SMTP						
Max	8.62(+11)	4.83(+13)	7.39(+11)	4.12(+13)	8.63(+11)	4.90(+13)
Min	4.85(+10)	2.71(+12)	1.61(+10)	8.97(+11)	4.89(+10)	2.76(+12)
FP						
Max	1.82(+11)	1.01(+13)	2.38(+9)	1.56(+11)	1.84(+11)	1.03(+13)
Min	7.84(+10)	4.39(+12)	1.03(+9)	6.73(+10)	7.94(+10)	4.46(+12)

* (+12) = 10^{12}

** BBRC Report (Reference 12).

*** At 10 hours into the decay curve

1) Baseline - all solar exposed Spacelab surfaces are coated with S13G thermal control paint.

2) The pallets are covered with graphite epoxy and externally exposed. The module is coated with S13G.

3) The pallets utilizing graphite epoxy are coated with S13G. The module is coated with S13G. To worse case this configuration, the composite mass loss rates are assumed to be additive (i.e. TML = mass loss S13G + mass loss graphite epoxy). With the panels coated with the thermal control coating, the mass loss will most likely be partially masked limiting the mass loss rates to a diffusion process. However, it was assumed for this option that the diffusion process will be sufficient to allow mass loss rates equivalent to those witnessed in the screening tests.

The following results present that portion of the induced contaminant environment contributed by the epoxy graphite panels for each Spacelab configuration.

Source Max/Min Temp	NCD (polar molecules/cm^2)		
	LMOP	SMTP	FP
Outgassing**			
Max	9.0(+8)*	1.0(+9)	2.4(+9)
Min	2.0(+8)	4.0(+8)	1.0(+9)
Offgassing***			
Max	9.5(+10)	1.1(+11)	1.6(+11)
Min	2.0(+10)	5.0(+10)	6.7(+10)

* (+8) = 10^8
** BBRC Report (Reference 12).
*** At 10 hours into decay curve.

The above results indicate that for the stated assumptions, the contamination impact of replacing the aluminum honeycomb panels on the pallet structures with graphite epoxy carboform 69 should be negligible to the total induced environment for the various Spacelab

configurations. In fact, the environment using the graphite epoxy (column 2 in the previous results) is decreased slightly for LMOP and SMTP and is lowered significantly for the FP configuration when compared with the baseline S13G coated configurations (column 1). Proportionately, the graphite epoxy contributes a relatively small percentage to the two Spacelab/module configuration predictions as can be seen by comparing the previous two results summation. For these cases, the mass loss of the S13G dominates the final results significantly and still exceeds the stated contamination control criteria of 10^{12} molecules/cm^2 for several cases. Even though the use of epoxy graphite paneling does not appreciably impact the environment itself, the total Spacelab induced environment resulting from the loss of mass from the modeled nonmetallic surfaces remains at a relatively high level. Currently a reevaluation of the mass loss characteristics of S13G is being conducted in conjunction with the MSFC Materials and Processes Laboratory. The results of this evaluation will need to be incorporated into the contamination computer model for a reassessment of the Spacelab induced environment.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions - As a result of this study, the following conclusions are presented.

a) Spacelab Thermal Control Material - There currently exist a wide variety of data on the outgassing and offgassing characteristics for the S13G white thermal control coating being assumed for use on a large portion of the Spacelab external surfaces. The baseline data utilized in the contamination model yields predictions for outgassing and offgassing that exceed the published contamination control criteria for number column density, return flux, and percent absorption due to condensibles. Conversely, outgassing and offgassing data supplied by the MSFC Materials and Processing Laboratory for the "clean" S13G used on the Skylab ATM canister results in predicted Spacelab contaminant levels that are well within all of the criteria except for the 1% absorption requirement. In order to meet this latter requirement for worst case situations, the Spacelab thermal control surfaces would have to demonstrate an effective outgassing rate less than 10^{-13} g/cm^2/second at 100°C assuming 100% area coverage. Until the large variation between these data are resolved with specific test data, the final impact assessment of Spacelab nonmetallic materials outgassing and offgassing can only be approximated within the variance of the input data. If the representative test data meets the 50M02442 (Reference 7) and SP-R-0022A (Reference 8) indications are that the NCD criteria will most likely be met. However, the return flux and percent absorption criteria may not be satisfied and will require individual evaluation. This can only be established from specific test data that currently is not available from 50M02442 and SP-R-0022A testing requirements.

b) Mission Compatibility Analysis - Based upon the current data available and the level of the analysis conducted to date, (with the institution of recommended operational timelines, constraints, and protective devices); the majority of Spacelab sources meet the contamination control requirements with the following exceptions:

1) Spacelab materials outgassing and offgassing which require further clarification of representative Spacelab SI3G source rates; and

2) the cabin atmosphere leakage and the Avionics Bay Vent which both exceed the return flux criteria at 200 km. (However, about 2.1% of this will condense at any temperature other than cryogenic and those instruments which in general have geometric acceptance angles small enough to limit the return flux level to a value below the criteria should have no problem).

In addition, there have been several areas identified which will require further special studies at a later point in time. These include such items as:

1) self contamination of free flyers;

2) geometric modeling of scientific instrument configurations to determine specific line-of-sight transport to and from Spacelab surfaces;

3) scientific instrument induced phenomena such as cryogenic boil-off gases, induced vehicle charging from ion/electron accelerators, and chemical cloud releases; and

4) launch and reentry impacts along with return cleanliness, refurbishment, and cleaning requirements.

Operationally, Spacelab white thermal control surfaces will experience varying degrees of degradation (i.e. increase in solar absorptivity) which could have a significant impact on Spacelab thermal control. In addition, the discoloration will be undesirable from an aesthetic point of view. The ultimate impact on thermal balance and refurbishment requirements are unknown until it is determined by ESRO what the degradation tolerances will be. This will also help establish any refurbishment requirements for Spacelab prior to subsequent launches.

For those instruments attempting to evaluate the ambient atmosphere in the vicinity of the Spacelab/ Shuttle Orbiter, the flux of some contaminant species will exceed the levels of similar species in the ambient flux even with all possible sources inhibited and timelined. The contamination control criteria currently does not cover this phenomena. To avoid such degradation, these instruments could be flown in a subsatellite mode.

c) Thermal Profile Data - Incorporation of the recent updated thermal profile data for the LMOP Spacelab configuration decreased the induced environment predictions by approximately one half. When similar data is obtained for the other two Spacelab configurations, it is anticipated that corresponding decreases will occur.

d) Trade Studies - The results of the trade studies conducted during this contract period indicated that little impact will result to the induced contaminant environment from replacing the Spacelab pallet aluminum honeycomb panels with graphite epoxy panels keeping in mind the limitations of the data supplied. The same was true for the impact of the Spacelab Avionics Bay Vent with the one exception that it exceeds the return flux criteria at 200 km altitude as explained in paragraph b above.

e) Modeling - Through communications with Dr. R. Naumann, NASA/MSFC, Chairman of the CRDG, it was his concensus that the contamination computer model utility is widely recognized and that it is a vital tool for contamination assessment and evaluation. A few areas for model refinement have been identified for development to improve its general applicability. These include: 1) treatment of the sticking coefficient for impinging outgassed molecules, 2) second surface source contributions to the column densities resulting from emitted contaminants incident upon a surface that do not stick; 3) use of updated S13G weight loss data; and 4) refinement of the 4100 hours e-folding time relationship for outgassing rate decrease as a function of vacuum exposure time.

f) Contamination Control Criteria - In conducting mission compatibility analyses and utilizing the SSPD (References 2 and 3) contamination criteria and the Spacelab contamination control requirements contained in Reference 1 to make final assessments, it became apparent that certain incompatibilities and difficulties in interpretation existed. It is realized that the intent of both sets of requirements is the same (i.e. to establish realistic contamination limits for the program to insure minimal impact to systems and scientific data from contamination). However, by comparing the sets of requirements, the inconsistencies become apparent. The Spacelab contamination control requirements are basically the limits for the Spacelab as a carrier based upon the majority of system and scientific instrument contaminant susceptibilities, while the SSPD pertains to each individual instrument and system by establishing the above requirements and determining if the requirements are adequate for each instrument. For convenience and ease of understanding, the two sets of requirements should be equivalent. In reviewing the requirements the following inconsistencies were noted:

1) The SSPD requirement for molecular column density limits all molecules to 10^{12} molecules/cm^2 while the Spacelab requirement limits only polar molecules to 10^{12} molecules/cm^2. In some cases, this could represent a two order of magnitude difference in molecular column density.

2) The Spacelab requirement for background brightness includes both scattering and emission in the near ultraviolet while the SSPD covers only scattered light with no reference to emitted radiation which is very important to infrared instruments or systems.

3) The Spacelab requirement for particle interference limits 10 micron or larger particles within a 4 arc minute half-angle field-of-view with 1 km

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while the SSPD limits 5 micron or larger particles within 10 km with no field-of-view specified.

4) The SSPD limits deposition on a surface to one monolayer with no regard to its impact, while the Spacelab requirements limit the return flux rate and absorption percentage resulting from condensibles on optical surfaces.

Data contained in the SSPD has been used as a basic tool for the mission compatibility analyses studies and the format in which the contamination control requirements are presented is not only confusing but also seems inadequate. As mentioned previously, the SSPD presents the requirement levels and then indicates whether or not the levels are adequate for each individual system or instrument. This is done as follows. A matrix is constructed in the SSPD with the instruments and systems listed down the left-hand column and the requirements listed across the top of a page. A symbol is placed at the matrix intersection of each requirement column and instrument/system line which equates to either 1) "required control is $\leq$ than the value specified" or 2) "required control is $>$ than the value specified." Interpretation of this is confusing. The current interpretation of these is 1) the contaminant level can be worse than or be equal to the stated requirement (i.e. contamination control need not be as tight) and that 2) the contaminant level must be better than the requirement respectively. However, the literal interpretation is just the opposite. For example, assume an instrument which must have less than 10^{12} molecules/cm^2 in its field-of-view to operate efficiently. In other words, control should be better than 10^{12} molecules/cm^2 and item 2) above would apply. It is felt that this was the intent of the method of presentation but this interpretation can be contested.

In addition, when item 1) above applies, it essentially means that no control is required at all (i.e. if the contaminant level can be greater than the

requirement, there is no limit on how much the requirement can be exceeded). This is somewhat unrealistic and greatly limits the utility of the SSPD in determining the contamination impacts of predicted contamination levels upon scientific instruments and systems which might be less susceptible to contamination than the stated requirements. Consequently, the Spacelab contamination control requirements were used when any question of interpretation or utility arose.

3.2 <u>Recommendations</u> - The following recommendations are made with respect to identifying those program considerations deemed important in implementing the required contamination control for those Spacelab/Payload configurations and missions and the related Shuttle Orbiter/Spacelab interfaces analyzed. The recommendations associated with the Spacelab carrier include:

a) To meet the intent of the criteria of less than 1% absorbtion due to condensibles on optical surfaces, one or possibly a combination of several of the following approaches should be considered:

   1) eliminate the use of nonmetallic thermal control material on Spacelab;

   2) select nonmetallic materials for Spacelab demonstrating an effective outgassing rate of less than 10^{-13} g/cm^2/second at 100°C;

   3) establish protective devices for sensitive instruments such as covers, sensitive surface heaters, and designs with small geometric acceptance angles; and

   4) reevaluate the need for a criteria as restrictive as the stated 1%.

b) Consideration should be given to conducting detailed materials mass loss testing on the S13G thermal control coating currently assumed to be used on Spacelab. This is necessary to clarify the large variation in existing

data and to determine mass loss rates more representative of S13G as applied specifically to Spacelab.

c) For major Spacelab nonmetallic materials (both those with significant surface areas and those located near sensitive surfaces), standard materials testing requirements should be expanded to include provisions for determining outgassing and offgassing rates as a function of time and temperature, sticking coefficients, contaminant species, and activation energies of deposits for the anticipated configuration and application to Spacelab.

d) White S13G type thermal control surface degradation resulting from outgassing deposition as severe as a 0.19 increase in solar absorptivity should be considered in the thermal designs of Spacelab and its sensitive Payloads.

e) The window covers on the Spacelab viewing and/or high quality windows should be closed at all times when the windows are not being used.

f) The Spacelab Avionics Bay Vent should be designed with a vent exit filter to limit particle emissions to less than 100 microns in size.

g) Sensitive payloads should utilize contamination protective devices where possible during the potential severe periods of launch, on orbit, reentry, and landing to minimize required ground refurbishment activities. These might include covers, aperture doors, surface heaters, or purges as applicable.

h) The applicability and design tolerances for contamination cleaning and ground refurbishment should be reviewed and developed for appropriate testing, cleaning procedures, and cleaning or refurbishment requirement criteria. This should include all the necessary testing of cleaning procedures on anticipated Spacelab contaminant deposits and surfaces to determine their utility and ultimate cost effectiveness over other refurbishment options as based upon relaunch cleanliness requirements.

i) An assessment of the contamination control criteria as set forth in the SSPD (References 2 and 3) as to its applicability and uncertainties in interpretation should be conducted. To be consistent with other program documentation, the SSPD requirements should be reassessed to reflect where applicable those similar requirements as established by the CRDG at MSFC.

j) Spacelab Configuration Contamination Model improvements should be established in those areas where necessary methodology developments are required to improve the fidelity of the contaminant predictions. These improvements should include, but not be limited to, the following:

   1) return flux contributions from contaminant self-scattering;

   2) second surface source characteristics for outgassing and offgassing;

   3) payload bay and adjacent area surface-to-surface deposition characteristics;

   4) return flux calculation techniques for surfaces with 2π steradian fields-of-view;

   5) mean free path influence upon mass and number column densities; and

   6) orbital variations that occur from numerous orbital altitude changes during a given mission.

k) Due to the current development status of the Spacelab Program, modifications in Spacelab source characteristics, configuration definitions, operational procedures, mission profiles, and contamination control criteria; continued review and reassessment will be required which will modify the results and recommendations of this study. In addition, current contamination control requirements have not been met in all cases and budget

allowances for individual systems (e.g. Spacelab, Shuttle Orbiter, External Tanks, etc.) have yet to be determined. Therefore, the following activities should be continued or initiated to provide continuity in providing contamination control for Spacelab:

1) continue configuration modeling including refinements and adjustments in configurations, source characteristics, and the Mission Profile Data Bank;

2) continue Spacelab mission compatibility analyses;

3) continue trade studies and model improvement studies;

4) initiate early Spacelab mission support planning requirements; and

5) initiate an activity to identify and develop the format and scope of activity required to transfer the contamination model to MSFC.

Those recommendations which establish an interface requirement with the Shuttle Orbiter include:

a) The Shuttle Orbiter payload bay doors should be closed during all operations of the OMS engines (especially during retro thrust maneuvers) to preclude any engine induced degradation to Spacelab and Payload surfaces.

b) Detailed analysis and supportive testing should be conducted to establish the potentials of particulate generation and effluent deposition from the OMS, VCS, 900 lb RCS engines, and the Shuttle Orbiter evaporator vents.

c) For specific Spacelab Payloads the VCS, evaporator and/or RCS should be inhibited to meet the intent of the contamination control requirements.

d) Shuttle Orbiter nonmetallic materials should be controlled to levels similar to those recommended for Spacelab to meet the 1% absorption criteria.

4. NOTES

4.1 References - The following references are presented to support the technical and programmatic material referenced in the text of this report.

1) JSC 07700 Vol. X and XIV, Revision C, "Space Shuttle Program Space Shuttle System Payload Accommodations," July 3, 1974, Lyndon B. Johnson Space Center.

2) "Summarized NASA Payload Descriptions - Sortie Payloads," Level A and B Data, July 1974, George C. Marshall Space Flight Center.

3) "Summarized NASA Payload Descriptions - Automated Payloads," Level A and B Data, July 1974, George C. Marshall Space Flight Center.

4) "Payload/Orbiter Contamination Control Requirement Study," MSFC NAS8-30452, MCR 74-93, May 1974, Martin Marietta Aerospace, Denver Division.

5) "Payload/Orbiter Contamination Control Requirement Study," MSFC NAS8-30755, Exhibit A, MCR 74-474, December 1974, Martin Marietta Aerospace, Denver Division.

6) "Payload/Orbiter Contamination Control Assessment Support," JSC NAS9-14212, MCR 75-13, June 1975, Martin Marietta Aerospace, Denver Division.

7) "ATM Material Control for Contamination Due to Outgassing," 50M02442, Rev. W, George C. Marshall Space Flight Center, March 1, 1972.

8) "Specification Vacuum Stability Requirements of Polymeric Material for Spacecraft Application," SP-R-0022A, Lyndon B. Johnson Space Center, Houston, Texas, September 9, 1974.

9) "A Screening Test Method Employing a Thermal Vacuum for the Selection of Materials to be Used in Space," ESRO PSS-09/QRM-02T (ESTEC), Issue No. 1, October 9, 1971.

10) Presentation to NASA on the "European Spacelab Design and Development Effort," Part C: Structures, ESRO/ ESTEC, July 1974.

11) Presentation to NASA on the "European Spacelab Design and Development Effort," Part F: ECS, ESRO/ESTEC, July 1974.

12) McPherson, D. G.: "Apollo Telescope Mount Extended Applications Study Program," CR-61173, Ball Brothers Research Corporation, May 25, 1967.

13) Technical Letter ASD-EP45-21360 (SO-E01Z-Para. VII), to: J. W. Littles, Chief, Life Support and Environmental Branch, MSFC; from: Thermodynamics and Propulsion Branch, Engineering Analysis Department, Aerospace Support Division, Teledyne Brown Engineering, Subject: Spacelab Configuration 4 Equilibrium Temperatures for Extreme Hot and Cold Orientations, January 6, 1975.

14) Memo EH01-MC-SL(75-09), to: Mr. Currie, MSFC, from: R. J. Schwinghamer, Director Materials and Processes Laboratory, MSFC, Subject: Spacelab Non-Metallic Materials Outgassing, March 7, 1975.

15) Robertson, S. J.: "Backflow of Outgas Contamination on to Orbiting Spacecraft as a Result of Intermolecular Collisions," Lockheed Report HREC-6554-2 LMSC-HREC D30600, Contract NAS8-26554, June 1972.

16) Miraca, R. F. and Wittick, J. S.: "Polymers for Spacecraft Applications," N67 40270, Stanford Research Institute, September 15, 1967.

17) Campbell, W. A., et al: "A compilation of Outgassing Data for Spacecraft Materials," NASA TND 7362.

18) Pochinaa, H. C.: "Vacuum Weight-Loss and Contamination Tests of Some Materials for Space Application," Proc. of the Fourth INTERNL. Vacuum Congress 1968.

19) Naumann, R. J.: "Shuttle TPS Panel Tests Preliminary Results" Working Paper, Space Sciences Laboratory, MSFC, January 16, 1975.

20) Dushman, S.: Scientific Foundations of Vacuum Technique, New York: John Wiley & Sons, Inc., 1962, p. 395.

21) Simons, G. A.: "Effect of Nozzle Boundary Layers on Rocket Exhaust Plumes," AIAA Journal, Vol. 10, No. 11, November 1972.

22) Chirivella, J. E. and Simon, E.: "Molecular Flux Measurements in the Backflow Region of a Nozzle Plume," J.P.L., JANNAF 7th Plume Technology Meeting, April 1973.

23) Scannapieco, J. F.: "The Effects of Outgassing Materials on Voltage Breakdown," JPL Technical Memorandum 33-447, Proceedings of the Second Workshop on Voltage Breakdown in Electronic Equipment at Low Air Pressure, March 5-7, 1969.

4.2 Abbreviations - The following abbreviations were used in this report and represent terminology relevant to this study and programs used to obtain supportive date for this study.

AFRPL	-	Air Force Rocket Propulsion Laboratory
AMPS	-	Atmospheric, Magnetospheric, and Plasmas in Space
BBRC	-	Ball Brothers Research Company
BET	-	Braunauer, Emmett, Teller
CMG	-	Control Moment Gyro
CRDG	-	Contamination Requirements Definitions Group

CSM	-	Command and Service Module
DOD	-	Department of Defense
ECR	-	Engineering Change Request
ECV	-	Environmental Condensate Vent
ESRO	-	European Space Research Organization
EVA	-	Extravehicular Activity
FP	-	Five Pallet Configuration
H	-	Atomic Hydrogen
H_2	-	Molecular Hydrogen
HE	-	High Energy
IPS	-	Instrument Pointing System
JSC	-	Lyndon B. Johnson Space Center
LEO	-	Gravity and Relativity Satellite
LMOP	-	Long Module/One Pallet
LOS	-	Line-of-Sight
MCD	-	Mass Column Density
MDF	-	Mission Data File
MMH	-	Monomethyl Hydrazine
MOL	-	Molecules
MPDB	-	Mission Profile Data Bank
MPL	-	Materials and Processes Laboratory
MSFC	-	Marshall Space Flight Center

N_2	-	Molecular Nitrogen
N_2O_4	-	Nitrogen Tetraoxide
NCD	-	Number Column Density
NH_3	-	Ammonia
OMS	-	Orbital Maneuvering System
QCM	-	Quartz Crystal Microbalance
RCS	-	Reaction Control Subsystem
RF	-	Return Flux
RGA	-	Residual Gas Analysis
RMS	-	Remote Manipulator System
RSI	-	Reusable Surface Insulation
RTV	-	Room Temperature Vulcanized
S	-	Sticking Coefficient
SEXSAT	-	Space Test Program Experiment Satellite
SCCM	-	Spacelab Configuration Contamination Model
SCV	-	Spacelab Condensate Vent
SMDF	-	Spacelab Mission Data File
SMTP	-	Short Module/Three Pallet
SPDF	-	Spacelab Payload Data File
SRB	-	Solid Rocket Booster
SSPD	-	Space Shuttle Payload Description Document

STDF	-	Spacelab Temperature Data File
TBD	-	To be determined
TCS	-	Thermal Control Surface
TML	-	Total Mass Loss
TOBE	-	Teleoperator Orbiter Bay Experiment
TPS	-	Thermal Protection System
TV	-	Television
VCM	-	Volatile Condensible Material
VCS	-	Vernier Control System
X-IOP	-	X Axis In the Orbital Plane
α_s	-	Solar Absorptivity
Å	-	Angstrom
^oC	-	Degrees Centigrade
cm	-	Centimeter
o	-	Degrees
ϵ	-	Emissivity
^oF	-	Degrees Fahrenheit
ft	-	Feet
g	-	Gram
^oK	-	Degrees Kelvin
kg	-	Kilogram
km	-	Kilometer

λ	-	Wavelength
lbs	-	Pounds
m	-	Mass
psi	-	Pounds per square inch

4.3 Definitions - The following definitions are presented to clarify terminology used in this report which reflect unique characterization of the principles, procedures, and methods of application that would be generally applicable to utilization of the results of this study.

a) Mass Column Density - The mass contained in a constant unit cross-sectional area extending from an origin to infinity, expressed in units of Mass/Unit Area.

b) Number Column Density - The number of molecules contained in a constant unit cross-sectional area extending from an origin to infinity, expressed in units of Molecules/Unit Area.

c) Flux - Mass flow through a unit area, expressed in units of Mass/Unit Area/Unit Time.

d) Line-of-Sight - The line being sighted from a critical surface and extending along a given direction of interest to infinity. Column densities are calculated along lines-of-sight.

e) View Factor - That fraction of the total mass leaving one surface that is capable of impinging upon another surface of interest in its field-of-view.

f) Return Flux - The mass flow of contaminants through a unit area reflected back to a surface of interest as a result of collisions with the ambient atmosphere expressed in Mass/Unit Area/Unit Time.

g) Outgassing - That contribution to contamination which comes from the material bulk characteristics and is long term in nature.

h) Offgassing -That contribution to contamination which is related to the volatiles which are either adsorbed to the material and/or carried in the preparation of a material and boil off very rapidly when exposed to vacuum.

i) Beta Angle - That angle between the orbit plane and the earth-sun line.

APPENDIX A

Mission 16 - High Energy Astrophysics

Contamination Assessment

CONTENTS

MISSION 16 CONTAMINATION ASSESSMENT

1. INTRODUCTION

This appendix establishes the contamination impact assessment for the OMS and VCS engines on the Mission 16 payloads for three engine operational modes. The modes are:

a) orbital insertion using the OMS engines;

b) CMG desaturation using the VCS; and

c) VCS experiment stabilization (no CMGs).

The Mission 16 payloads are: the HE-11-S X-ray Angular Structure and the SO-03-A Solar Maximum Satellite. The HE-11-S primary instrumentation consists of X-ray proportional counter and scintillation counter detection systems observing stellar targets in the 1-300 keV energy region. This Payload also contains an ultraviolet/visible tracker/field monitor telescope to facilitate Payload pointing and guiding and to provide aspect data. The Payload will be operated from the payload bay and its external surfaces and primary instrumentation will be susceptible to engine contamination.

The SO-03-A Payload consists of instrumentation designed to observe the sun. Since this is an automated Payload, its primary instrumentation will not be operated in the vicinity of the Shuttle Orbiter and consequently not be susceptible to engine contamination. It will also be assumed that the instrument aperture doors will remain closed during checkout and deployment. Therefore, for this analysis, only the external Payload surfaces will be considered susceptible to engine contamination while contained in the payload bay.

The results of this analysis are presented in the following section.

2.0 STUDY RESULTS

2.1 Orbital Insertion Using the OMS Engines - The deposition on the Payloads in the payload bay due to OMS engine burns will be primarily due to return flux since no direct line-of-sight exists between the Payloads and the engines. Some backflow will probably occur but worst-case analyses show that the backflow deposition will be negligible compared to the return flux deposition. Only external deposition will be considered since it is assumed that the experiment aperture doors will be closed during OMS burns.

The computer math model was used to calculate the return flux deposition. Three engine burns were assumed (orbit circularization at 315 km and 500 km and transfer to 500 km from 315 km). The total deposition on the front end of the Payloads was determined to be 1.8×10^{-7} g/cm^2 (18 Å). Lewis Research Center test data for S13G thermal control paint shows that this amount of engine deposition will cause negligible degradation to white thermal control surface performance.

2.2 CMG Desaturation Using VCS - The deposition on Payloads in the payload bay due to VCS operation will be due to return flux only since no line-of-sight exists between the Payloads and engines. Only external deposition was considered since it was assumed that the experiments will not be operating during CMG desaturation maneuvers and the scientific instrument aperture doors will be closed. Other assumptions are: 1) 5.6 lbs of VCS propellant will be required for 6 engines for each maneuver; 2) one desaturation maneuver will be required every 9 orbits; and 3) the maneuvers will be performed during the orbital period of maximum return flux (worst case).

The total deposition due to 6 engines firing for equal time periods was calculated using the computer math model for the front of the HE-11-S Payload. The deposition for a single maneuver was determined to be 8.8×10^{-11} g/cm^2 (0.0088Å). For a six day mission (9 maneuvers), the deposition was determined to be 8.0×10^{-10} g/cm^2 (0.08 Å). This amount of deposition will not cause measurable degradation to any external Payload surfaces.

2.3 VCS Experiment Stabilization - The contamination impact of the VCS engines when used for experiment stabilization consists of quasi steady-state molecular column densities in addition to return flux deposition. Deposition will occur on both internal experiment surfaces and external Payload surfaces. Mass and number column densities were calculated along the Payload line-of-sight assuming that five lbs of VCS propellant would be used per orbit by 6 engines with one engine firing every 4.8 seconds. The mass column density was determined to be 1.0×10^{-9} g/cm^2. This corresponds to a number column density of 3.4×10^{13} molecules/cm^2 assuming an average molecular weight of 18. The specific degradation of HE-11-S performance due to these column densities is unknown at this time. Inflight contamination control criteria in the SSPD[1] indicates the

(1) "Summarized NASA Payload Descriptions - Automated Payloads," Level B Data, July 1974, George C. Marshall Space Flight Center

control required is less than 10^{12} molecules/cm^2. How much less is unknown at this time. The Spacelab contamination control criteria limits the polar molecular number column density to 10^{12} molecules/cm^2. The VCS induced polar number column density will be approximately 1.3×10^{13} molecules/cm^2 which exceeds the criteria appreciably. However, negligible degradation is anticipated for typical high energy Payloads.

The mass column density was used to calculate the return flux. Assuming that the Payload line-of-sight was in the orbital plane (worst case), the total return flux deposition from the 6 engines on the front end of the Payload was determined to be 2.2×10^{-10} g/cm^2/orbit and 2.2×10^{-8} g/cm^2/6 days (2.2 Å/6 days). Lewis test data shows that for S13G this amount of deposition (2.2 Å) will cause negligible degradation. For a typical experiment, assuming a full acceptance angle of 28°, the return flux deposition was determined to be 6.4×10^{-12} g/cm^2/orbit and 6.2×10^{-10} g/cm^2/6 days. This amount of deposition will not cause significant degradation to the internal surfaces of the HE-11-S Payload.

2.4 Summary - The results of these analyses indicate negligible degradation due to deposition to the Mission 16 Payloads caused by the OMS burns, by VCS operation during CMG desaturation, and by VCS usage for experiment stabilization. The number column density induced during VCS operation exceeds the 10^{12} polar molecules/cm^2 criteria, but the impact should be small for the Mission 16 scientific instruments.

APPENDIX B

Mission 10 - Pallet Flight Test Verification

Contamination Assessment

CONTENTS

MISSION 10 CONTAMINATION ASSESSMENT

1. INTRODUCTION

This appendix establishes the on orbit operational phase contamination impact analysis for the identified Mission 10 Payloads. Although it is realized that the prime objective of this mission is the Spacelab Pallet Flight Test Verification, scientific data will be gathered as a secondary objective and the contaminant environment should be evaluated. Analysis contained herein will, in addition, be applicable to similar Payloads flown on ensuing scientific data gathering missions. The combined Spacelab/Shuttle Orbiter contamination model was used as the basis for this analysis. Identified major Spacelab/Shuttle Orbiter contamination sources were also used for this analysis. No consideration was given to the specific Payload geometries and to the Payloads as potential sources of contamination. Only Option V which includes the AP-04-S, HE-11-S, SO-703, and EO-703 Payloads was analyzed since it best represented the Payloads being considered and also provided maximum Payload use time which would relate to maximum or worst case contaminant potential.

The LEO satellite (AP-04-S) consists of precision cryogenic gyroscopes held at approximately 1.6°K for a one year operational period. In addition it contains a star telescope, star tracker, and infrared earth horizon sensor for reference orientation. These all have protective covers which should be used during launch, ascent, and while attached to the Shuttle Orbiter. These covers should provide adequate internal protection for LEO during its attachment to the Spacelab pallet. LEO is also deployed very early upon achieving the desired orbital altitude. Therefore, the external surfaces of LEO will not be impacted by the induced contaminant environment during this short period. The deployment scheme for LEO is unknown at this time. Regardless of the deployment scheme chosen, primary LEO thrusters for achieving its final orbital altitude should not be fired in the near vicinity of the Shuttle Orbiter.

The HE-11-S Payload consists of 4 proportional counters, 7 scintillation counters, one optical telescope, and one tracker/field monitor. All of these require inflight contamination protective covers as per the SSPD[(1)] and these should provide adequate protection for these instruments when they are not in use.

The SO-703 payload consists of a fairly large coelostat mirror, a 65 cm photoheliograph, a hydrogen alpha image tracker,

(1) "Summarized NASA Payload Descriptions - Automated Payloads," Level B Data, July 1974, George C. Marshall Space Flight Center.

an electronic camera, an echelle spectrograph, and a magnetograph filter. For this mission, it appears that the most susceptible Payload will be the SO-703. The coelostat mirror will be the most susceptible element of this Payload. The SO-703 spectral range is in the ultraviolet ($\lambda = 1500\text{Å}$) and visible wavelengths which makes it especially susceptible to absorption by deposition on the coelostat mirror. The coelostat will be almost totally exposed to the Spacelab/Shuttle Orbiter induced contaminant environment. This reflective surface has a relatively large field-of-view (up to approximately 2π steradians in some occulted positions) and therefore will be directly exposed for long periods of time to the induced environment. Identified temperature maximum data for the mirror (287 to 299°K) implies that during warm portions of an orbit (when Spacelab/Shuttle Orbiter outgassing surfaces are warmer than the mirror) some of the contaminant will be able to stick.

Because of the spectral range of the EO-703 Mark II Michelson interferometer spectrometer (detecting in the 1 to 10 micron region) and with its objective of earth atmosphere trace constituent measurements, it will not be particularly susceptible to the Spacelab/Shuttle Orbiter induced contaminant environment.

The following analysis presents the contamination impact assessment for the SO-703 coelostat mirror and the remaining system surfaces which may be affected by the anticipated induced contaminant environment. Presented as part of this analysis is the predicted contaminant environment for the on orbit contamination monitor. This is presented only to begin to establish correlation between the contamination modeled environment and that to be measured by the inflight contamination monitor on Mission 10.

2.0 STUDY RESULTS

2.1 Launch Through Orbital Insertion Contamination - The contamination potential and impact of the OMS engines on the Mission 10 Payloads were analyzed for the two orbital insertion translation maneuvers (between 55 km and 185 km and between 185 km and 460 km) and the orbit circularization maneuvers at 185 and 460 km. Deposition on Payload surfaces from these engines results primarily from the return flux of engine effluents in the backflow region through their interaction with the

ambient atmosphere. The following table depicts the predicted deposition levels on the +Z facing Payload surfaces from the analyzed maneuvers, along with the corresponding film thicknesses assuming a specific gravity of 1.0 for the deposit. Contaminant sticking coefficient values were derived from MMH/N_2O_4 engine testing at Lewis Research Center and data acquired during the Skylab mission.

Orbital Maneuver (km)	Estimated Propellant Usage (kg)	Deposition	
		(g/cm^2)	(Å)
55 to 185	760	~0*	~0*
185 circular	1,249	1.48×10^{-6}	148
185 to 460	2,513	2.3×10^{-7}	23
460 circular	2,425	2.7×10^{-8}	2.7
TOTALS	6,947	1.74×10^{-6}	173.7

* Mean free path of engine effluents in this altitude range equals only a few centimeters, therefore engine backflow will be swept away before it can reach vicinity of the Spacelab and Payloads.

The predicted deposition levels could degrade the critical optical surfaces of Payloads detecting in the ultraviolet region if exposed during the OMS maneuvers. The SO-703 coelostat assembly should either be packaged during launch and installed after insertion or be provided with in-place launch protection. On all other Payloads, aperture covers and contamination protection devices should be in position to preclude deposition on sensitive surfaces. OMS engine deposition will cause an increase in the solar absorptivity (α_s) of S13G type white thermal control paints, however, Lewis Research Center test data indicates that for the levels predicted this degradation should be less than a few percent. Also, the resulting power loss to the AP-04-S LEO satellite solar arrays should be negligible.

2.2 On Orbit Contamination - Once the Mission 10 Spacelab/Shuttle Orbiter vehicle has achieved the desired 460 km orbit, several additional contamination sources and phenomena should be considered. These include, but may not be limited to, the following major items that have been identified to date:

a) outgassing deposition from the vacuum exposed non-metallic surfaces of the Spacelab/Shuttle Orbiter;

b) Shuttle Orbiter 25 lb and 900 lb thrust Reaction Control System (RCS) engine exhaust effluent deposition;

c) induced contaminant molecular environment resulting from the significant contaminant sources analyzed;

d) random particle emission from the Spacelab/Shuttle Orbiter surfaces; and

e) contaminant levels for the on orbit contamination monitor package for the above sources.

2.2.1 Outgassing of Spacelab/Shuttle Orbiter Nonmetallic Surfaces - The return flux of outgassed effluents was determined for the scientific instrument and operational surfaces of Mission 10 through use of the contamination computer model. This analysis indicated that by far the most susceptible instrument to return flux deposition of outgassed molecules would be the SO-703 and in particular the coelostat mirror assembly. Model predictions were worse cased using the following assumptions:

a) Solar Inertial/X-IOP attitude at 460 km altitude;

b) Average beta angle = 60°;

c) Coelostat temperature = $294^{\circ}K$;

d) Estimated coelostat acceptance angle = 83° total with mirror fixed at 45° off of the Shuttle Orbiter +Z axis.

Based upon available Spacelab/Shuttle Orbiter thermal data, approximately 2.1×10^{-8} g/cm^2/orbit (2.1 Å/orbit) will deposit on the mirror during periods of mirror exposure. This equates to a data attenuation of greater than 1% after only two orbits of exposure in the 1500 Å wavelength region which exceeds the requirements of applicable document JSC 07700[2] for signal loss due to condensible contamination. For the ~3-1/2 day planned

(2) JSC 07700 Vol. XIV, Revision C, "Space Shuttle Program Space Shuttle System Payload Accommodations", July 3, 1974, Lyndon B. Johnson Space Center.

operation of SO-703, signal attenuation at 1500 Å due to coelostat reflectance loss would be ~34% considering continuous mirror exposure. Although Mission 10 is primarily a systems evaluation mission, the level of degradation indicated would also result for scientific data gathering missions. Therefore, some modifications are required.

Consideration should be given to the following recommendations to decrease deposition levels on the coelostat:

a) thermally control the mirror temperature to a value above that of the Spacelab/Shuttle Orbiter outgassing sources (~ 50 to 75°C) contributing to the return flux;

b) decrease the geometric acceptance angle of the coelostat through extension of the walls of the mirror mounting structure in the Shuttle Orbiter +Z direction;

c) avoid vehicle attitudes which allow return flux to the mirror during warm portions of an orbit; and

d) available reference material does not indicate any protective covers for the coelostat. If this is the case, a cover should be designed that can and should be closed to protect the mirror when data is not being taken.

For the levels predicted, outgassing should be of little impact to the EO-703 interferometer operating in the less susceptible 1-10 micron range or the HE-11-S High Energy Astrophysics and star tracking systems.

For its relatively short stay in the Shuttle Orbiter payload bay during the early on orbit period, the AP-04-S LEO satellite will experience some deposition due to outgassing. The impact will be mainly on the solar arrays and thermal control surfaces, however, this is felt to be negligible. Protective covers as required per SSPD documentation should be used while AP-04-S is in the payload bay. After deployment the LEO itself will continue to outgas and when considering the extent of the mission

(~ 1 year) outgassing might impact the star telescope, star tracker, and to a lesser degree the infrared horizon sensor. Degradation to external thermal control surfaces may result in an increased helium requirement to keep the gyros at cryogenic temperatures thus decreasing the satellite's lifetime. For these reasons, detailed analysis and modeling of AP-04-S as a free flyer should be considered at a later date.

2.2.2 <u>25 lb and 900 lb Thrust Reaction Control System (RCS)</u> - Degradation to Mission 10 operational and scientific instrument surfaces can result from use of the 25 lb Vernier Control System (VCS) for Shuttle Orbiter/scientific instrument stabilization and from use of the 900 lb RCS for attitude maneuvers and AP-04-S deployment. Return flux deposition from these thrusters was determined based upon anticipated fuel usage requirements of 740.4 lbs for the VCS and 895 lbs for the 900 lb thrust RCS. The resulting deposition levels from operations of all the RCS thrusters will be approximately 1.1×10^{-9} g/cm^2 in 3 1/2 days on the SO-703 coelostat and 9.2×10^{-9} g/cm^2 in 7 days for the +Z facing operational surfaces. This indicates negligible impact to the Mission 10 Payloads in the payload bay due to RCS deposition. During deployment of the AP-04-S significant impingement can result on the satellite from the 900 lb thrusters. To avoid this, consideration should be given to inhibiting certain engines during the deployment operations or to establishing alternate deployment schemes to avoid impingement.

2.2.3 <u>Induced Molecular Contaminant Environment</u> - Molecular mass and number column densities along a line-of-sight parallel to the Shuttle Orbiter +Z axis were calculated for the previously discussed on orbit contaminant sources (i.e., materials outgassing and the 25 lb thrust VCS) and the additional sources of materials offgassing (the release of light gases, vapors, and volatiles), atmosphere leakage, and the Shuttle Orbiter evaporator vents. The predicted molecular number column densities (NCD) are summarized below:

Contaminant Source	Total NCD (mol/cm^2)	Polar NCD (mol/cm^2)
Outgassing MAX*	$3.1x10^{11}$	$3.1x10^{11}$
MIN	$1.1x10^{11}$	$1.1x10^{11}$
Offgassing MAX	$1.2x10^{13}$	$1.2x10^{13}$
MIN	$5.5x10^{12}$	$5.5x10^{12}$
Cabin Leakage	$2.2x10^{13}$	$4.6x10^{11}$
Evaporator**	$6.3x10^{13}$	$6.3x10^{13}$
VCS Aft-Z	$4.4x10^{14}$	$2.4x10^{14}$
Aft±Y	$2.0x10^{14}$	$1.1x10^{14}$
Fwd-Z	$3.9x10^{12}$	$2.2x10^{12}$

* MAX/MIN indicates the maximum and minimum temperature thermal profiles used in the analysis.

** Thruster

The specific degradation of the Mission 10 Payloads' performance due to these column densities is unknown at this time. Inflight contamination control criteria in the SSPD[3] indicates the control required for HE-11-S is ≤ to 10^{12} molecules/cm^2. How much less is presently an unknown. Sufficient configuration and sensitivity data was not available to analytically determine NCD limits for any of the Mission 10 Payloads at this time. However, negligible degradation is anticipated for typical high energy, solar, and interferometer Payloads for the levels predicted.

Of additional concern during the first few orbits of this mission is materials offgassing which may induce pressures high enough to create the potential of corona arc-over at high voltage power supplies. In specific corona susceptible areas, realtime ion pressure gages should be installed to monitor pressure decay to allow the safe timelining of high voltage system activations.

2.2.4 Random Particle Emission - The contaminant influence of the random emission of particles from the surfaces of the Shuttle Orbiter and Spacelab can be qualitatively assessed from

(3) "Summarized NASA Payload Descriptions - Sortie Payloads," Level B Data, July 1974, George C. Marshall Space Flight Center.

observations made by the Skylab white light coronagraph experiment. This data indicated that Skylab demonstrated a quasi steady state emission rate of ~ 60 particles/second ≥ 10 to 25 microns (4.78 particles/steradian/second). Since Skylab and the Shuttle Orbiter/Spacelab configurations have essentially equal surface areas ($\sim 13{,}000$ ft^2), this rate is used in the analysis. However, due to the reusability of the Spacelab/ Shuttle Orbiter and the numerous gimballed systems employed, the rate could be considerably higher for the Mission 10 Payloads. In as much as current criteria limits this rate to ~ 547 particles/second >10 microns, the rate deduced from Skylab is well within tolerance.

Although sufficient detail is not yet available on Payload configurations and sensitivities to perform a detailed analysis, preliminary assessment of the Payloads is possible. The results are presented below.

a) SO-703 - For the effective field-of-view of 180 $\widehat{\text{sec}}$ as stated in the SSPD, approximately one particle each 65 orbits would pass through the field-of-view of the photoheliograph, which is negligible. In addition, this would probably not be detectable due to the brightness of the instrument target (i.e., the sun).

b) HE-11-S - The stated fields-of-view of the scintillation counters, the optical telescope, and the trackers of 5° will allow ~ 154 particles/orbit to be detected assuming the instruments are sensitive enough to detect particles in the stated size range. This does not exceed the criteria of 1 particle >10 microns in a 4 $\widehat{\text{min}}$ half-angle field-of-view which equates to 1406 particles in the 5° field-of-view per orbit. The particles are not expected to impact the scintillation counters. However, false star tracking could be induced as was experienced during the Skylab mission. This possibility can be reduced appreciably by decreasing star tracker sensitivity thresholds to allow acquisition of only bright target stars and by limiting star reference updating to minimum periods of time.

c) EO-703 - Limited data was available on this Payload configuration, however the impact of particles on the interferometer data is expected to be negligible. Anomalous data created by particulate contamination can most likely be subtracted from the valid flight data.

d) AP-04-S - Particles will not effect the LEO satellite in the payload bay although self-induced particles from the satellite as a free flyer could result in false star tracking. This phenomena should be investigated in detail due to stringent pointing requirements of 0.05 seconds and previous flight experience of false star tracking by sensitive reference systems.

2.2.5 On Orbit Contamination Monitor Package - The on orbit contamination monitor package will consist of instrumentation to detect deposition levels and the contaminant cloud thickness (molecular column density) in the vicinity of the payload bay. The model predictions contained herein should be useful in beginning to establish correlation between the modeled contamination environment and that to be measured during Mission 10. For the purposes of this analysis, two types of deposition detectors were assumed. One detector held at 25^{o}C having an acceptance angle of 90^{o} viewing in the +Z direction and the second detector having the same geometric assumptions and held at a low enough temperature to assure a unit sticking coefficient for all contaminants except light gases (N_2 and O_2). Following are the predicted levels for these detectors.

Source	Deposition (g/cm^2/orbit)	
	25^{o}C Detector	Cold Detector
Outgassing	4.0×10^{-8}	2.0×10^{-7}
Offgassing	0	1.7×10^{-8}*
Leakage	0	2.8×10^{-9}
Evaporator	0	1.6×10^{-7}
RCS	2.4×10^{-11}	1.2×10^{-10}
OMS	3.8×10^{-8}**	1.9×10^{-7}**

* First 100 hours only (average)
** Total for 4 burns at insertion

Therefore, for a 7 day mission ($\sim$ 112 orbits), the 25^{o}C deposition detectors should see $\sim 4.5 \times 10^{-6}$ g/cm^2 resulting basically from outgassing, and the cold detectors should see $\sim 4.2 \times 10^{-5}$ g/cm^2 which is about half outgassing and half condensed water vapor.

The molecular mass and number column densities above the contamination monitor package parallel to the Shuttle Orbiter +Z axis will vary appreciably with the operational activities of the Shuttle Orbiter/Spacelab from a maximum of 5.4×10^{14} molecules/cm^2 (3.5×10^{14} polar molecules/cm^2) during high outgassing, offgassing, and evaporator operational periods with the VCS firing to a minimum of 2.8×10^{13} molecules/cm^2 (6.0×10^{12} polar molecules/cm^2) during low outgassing and offgassing when the evaporator and VCS are not operating. It should be noted that under the conditions stated and the modeling assumptions used that the criteria of 10^{12} polar molecules/cm^2 stated in JSC 07700[(2)] is exceeded in all cases.

2.3 Optional Configurations - Two options of the baselined Mission 10 were also analyzed for contamination influences. These included Option A (rectangular HE-11-S with the ESRO Instrument Pointing System (IPS)) and Option B (circular HE-11-S without the IPS). The study indicated that there would be little or no impact from the use of these options to the previous contamination analysis for the basic Mission 10 configuration (circular HE-11-S with the IPS). Option A will potentially induce a slightly higher density particulate environment than will Option B due to the multiple gimbal nature of the IPS system, but this impact is expected to be negligible. Conversely, the hard mounted HE-11-S configuration of Option B should result in a somewhat lower level of particulate generation than either the basic mission or Option A. However, with no gimballing capability, Option B will most likely require increased usage of the Shuttle Orbiter 25 lb thrust VCS engines for instrument pointing. Until explicit deadband requirements for HE-11-S pointing and attitude hold are known in this mode, the ultimate impact cannot be determined. The 25 lb VCS will potentially contaminate the Mission 10 Payloads both from the deposition of emitted effluents on Spacelab and scientific instrument surfaces and from the contaminant "cloud" resulting from engine firings through which the scientific instruments must view. For this reason, options which

(2) JSC 07700 Vol. XIV, Revision C, "Space Shuttle Program Space Shuttle System Payload Accommodations," July 3, 1974, Lyndon B. Johnson Space Center.

would require increased VCS usage significantly should be avoided. Therefore, from a contamination viewpoint, the configurations employing their own pointing systems (i.e. the basic Mission 10 and Option A) would be the most desirable.

2.4 Summary - The results of these analyses indicate several areas of concern related to the contaminant effects of the Spacelab/Shuttle Orbiter upon the Mission 10 Payloads. These include the deposition of outgassing upon the SO-703 coelostat and the potential tracking of "false star" particulates by the HE-11-S star trackers. These effects can be significantly reduced through proper design modifications and/or operational timelining and constraints. Other sources including the deposition of OMS and VCS engine effluents appear to yield only negligible degradation to critical optics (if proper covers are employed) and operational surfaces.

The predicted contaminant molecular number column densities along the Payload lines-of-sight in all cases exceed the contamination criteria stated in JSC 07700[2]; however, the final impact of these levels on the scientific data of the Mission 10 Payloads is unknown at this time although it is expected to be small. This area requires further investigation.

Of the two configuration options analyzed, Option B appears to be the least desirable due to it potential increased VCS fuel usage requirement for HE-11-S pointing.

(2) ibid

APPENDIX C

Mission 19a - Atmospheric, Magnetospheric, and Plasmas in Space (AMPS)

Contamination Assessment

CONTENTS

MISSION 19a CONTAMINATION ASSESSMENT

1. INTRODUCTION

This appendix establishes the contamination impact analysis conducted for the Mission 19 Option A Spacelab/Atmospheric, Magnetospheric, and Plasma in Space (AMPS) Shuttle Orbiter mission. In general, when analyzing the influences of contamination upon a particular Spacelab mission two major categories require detailed assessment. These include, first, the contaminant impact of the particular mission activities and operations upon Spacelab unique hardware and, secondly, the induced contaminant environment created by the mission peculiar hardware and its ultimate impact upon the scientific instruments' ability to collect valid data. For the purposes of this analysis, it has been assumed that the Spacelab hardware (i.e. module, pallet, tunnel structures, etc.) has been completely refurbished from previous flights and is in "first launch" condition prior to the Mission 19a flight. The basis for this analysis was the combined Spacelab/Shuttle Orbiter contamination computer model, previous ground test and flight data, and published contamination control criteria included in the applicable documents JSC 07700[1] and the SSPD[2]. Due to the complexity of the Mission 19a Payload configuration and mission profile, basic assumptions have been made in an effort to simplify the analysis. This inherently limits the resolution of the predictions but not to the degree that final conclusions and recommendations are influenced significantly.

The threat of contamination will be present throughout all of the operational phases of the Mission 19a flight. In response to this fact, the analysis in the following sections covers the primary mission phases of launch, on orbit operations, and reentry. It is obvious that some contamination effects such as deposition will be accumulative throughout all of the mission phases and that no one phase should be considered separately. However, for the sake of organization and in order to isolate specific contamination phenomena, the analysis covers each operational phase separately. All major contaminant sources delineated in MCR 74-474[3] have been investigated for this analysis with only those deemed significant to the Mission 19a Spacelab and scientific instruments mentioned herein.

(1) JSC 07700, Vol. XIV, Revision C, "Space Shuttle Program Space Shuttle Payload Accommodations," July 3, 1974, Lyndon B. Johnson Space Center.

(2) "Summarized NASA Payload Descriptions - Sortie Payloads," Level B Data, July 1974, George C. Marshall Space Flight Center.

(3) MCR 74-474, "Payload/Orbiter Contamination Control Requirement Study," December 1974, Martin Marietta Aerospace, Denver Division.

The main objective of the contamination control for any Spacelab mission is to insure not only that the scientific instruments can obtain desired data unimpaired by contamination effects but also that the accumulative impact of the induced environment upon Spacelab and the scientific instrument sensitive surface be minimized to insure the success of the ongoing mission as well as ensuing missions which require the reuse of the Mission 19a hardware. If controls are inadequate, extensive ground refurbishment will be required on the reusable hardware. In general, the Spacelab hardware will be only susceptible to the deposition of contaminant effluents on critical surfaces (i.e. thermal control surfaces and windows) while the scientific instruments, in addition to deposition, will be susceptible to the thickness and constituents of the contaminant cloud and the induced particulate environment plus unique items such as coronal discharge and charge accumulation resulting from electron and ion accelerator operations. The analysis of these items is covered in the following subsections.

2.0 STUDY RESULTS

2.1 Launch Through Orbital Insertion Contamination - Throughout the launch phase of Mission 19a several operations will occur which may create possible high risk potentials of contamination of the Spacelab/scientific instrument sensitive surfaces within the payload bay of the Shuttle Orbiter. These include the contamination potentials resulting from 1) ingestion of contaminants into the active vents; 2) Solid Rocket Booster (SRB) separation rocket exhausts; and 3) Orbital Maneuvering System (OMS) engine firings for final orbital insertion. These are covered in the following paragraphs.

Attitude maneuvers during the high dynamic pressure regime incurred during launch will create enough pressure variation across the active vents to allow the external environment to be ingested into one vent and flow out of another presenting a potential contamination problem. Launch vibrations and the aerodynamic heating that occurs during the maximum dynamic pressure regime will cause the release of contaminants from the external Shuttle Orbiter and launch vehicle surfaces that are capable of being ingested into the bay. The 35 micron filtered active vents should preclude the ingestion of most of the larger particulate matter. This should be a short term

phenomena and although the impact of this will be negligible to the Spacelab critical surfaces, the sensitive AMPS scientific instruments require additional protection. The SSPD recommends protective covers for the AMPS optical sensors, electro-optical sensors, energetic particle detectors, plasma devices, and mass spectrometers. These should be incorporated into the scientific instrument designs and held in a closed position throughout all launch/orbital insertion operations.

SRB separation will be accomplished by small retro rockets which can develop pressures on the external Shuttle Orbiter surfaces as high as 5 psi. During this operation, it is recommended that the active payload bay vents be closed to preclude the ingestion of exhaust effluents into the bay. Exhaust products will be able to enter the passively vented Shuttle Orbiter cavities and may deposit on external surfaces to be reemitted later in the mission.

After main engine cut off, the External Tank will be released and the OMS will be fired for approximately 38 seconds consuming 1636 lbs of fuel to insert the Shuttle Orbiter into a 60x185 km elliptical orbit. The payload bay doors will then be opened exposing the radiators to support Shuttle Orbiter cooling. During the two successive OMS firings for orbit circularization at 185 km and the Hohmann transfer to a 185x425 km elliptical orbit, the payload bay doors are scheduled to remain open. These two maneuvers will consume approximately 2449 lbs and 4846 lbs of MMH/N_2O_4 fuel respectively. Deposition on Spacelab/scientific instrument surfaces from these engines will result primarily from the return flux of engine effluents in the backflow region through interactions with the ambient atmosphere. This backflow phenomena has been tested by Chirivella[4] and treated analytically by Simons[5] and others. Based upon contaminant sticking coefficient values derived from Lewis Research Center MMH/N_2O_4 engine testing and data derived from Skylab, approximately 8.2×10^{-7} g/cm^2 will deposit on the +Z facing Spacelab surfaces assuming the deposits experience ultraviolet radiation. Although the resulting increase in

(4) Chirivella, J. E. and Simon, E.: "Molecular Flux Measurements in the Backflow Region of a Nozzle Plume," J.P.L., JANNAF 7th Plume Technology Meeting, April 1973.

(5) Simons, G. A.: "Effect of Nozzle Boundary Layers on Rocket Exhaust Plumes," AIAA Journal, Vol. 10, No. 11, November 1972.

solar absorptivity of the Spacelab S13G type white thermal control paint will be less than a few percent, consideration should be given to closing the payload bay doors during these OMS firings to eliminate the degradation completely and to protect the exposed scientific instrument housings. Although the potential degradation to the Spacelab thermal control surfaces is small, consideration must be given to subsequent reflight and refurbishment requirements for the thermal control surfaces and any other critical operational surfaces. Indications are that the Shuttle Orbiter evaporator system can easily handle the vehicle heat loads with the doors closed during these maneuvers.

2.2 On Orbit Contamination - Once the Mission 19a Spacelab/Shuttle Orbiter vehicle has achieved orbit, several additional contamination sources and phenomena must be considered. These include, but may not be limited to, the following major items that have been identified to date:

a) outgassing deposition from the vacuum exposed nonmetallic surfaces of the Shuttle Orbiter/Spacelab;

b) Shuttle Orbiter 25 lb and 900 lb thrust Reaction Control System (RCS) engine exhaust effluent deposition;

c) Orbital Maneuvering System (OMS) engine exhaust effluent deposition;

d) induced contaminant environment, both molecular and particulate, resulting from the significant contaminant sources analyzed; and

e) other on orbit considerations including subsatellite, ion and electron accelerator, and barium cloud impact.

The analyses of these are discussed in the following subsections. Additional known sources which are not mentioned are felt to have only second order effects based upon the relative magnitudes of anticipated flux rates or due to the fact that the contaminant species are not expected to stick to critical surfaces at their estimated temperatures.

2.2.1 Outgassing Deposition - There are two basic mechanisms by which outgassed species may be transported between surfaces. These are direct line-of-sight and return flux resulting from interactions with the ambient atmosphere. Both mechanisms were investigated for their potential impacts to the scientific instruments and operational surfaces of Mission 19a through use of the contamination computer model. Direct line-of-sight deposition between most Spacelab, scientific instrument, and Shuttle Orbiter surfaces was found to be negligible since, with current thermal data, most of the surfaces that can "see" each other are at similar temperatures at similar times resulting in a small net deposition between them. With higher resolution temperature data this fact may be altered and additional analysis may be required. Direct line-of-sight deposition was calculated for the two Spacelab windows. The analysis indicates that (assuming that the windows are left uncovered for the entire on orbit portion of the mission) the +Z facing high quality window will experience $\sim 2\times10^{-10}$ g/cm^2 deposition (negligible transmission loss) and the aft conical section viewing window will experience $\sim 1.1\times10^{-5}$ g/cm^2 deposition which equates to a 2% transmission loss to the photopic eye. This can be reduced considerably by closing the external cover whenever the window is not in use.

For the anticipated mission profile and configuration of Mission 19a, the primary deposition mechanism will be the result of return flux of the outgassed contaminants. Selected Spacelab and scientific instrument surfaces were chosen for analysis in an attempt to encompass the majority of anticipated deposition levels. These included the +Z facing Spacelab high quality window, the Spacelab aft conical section viewing window, the core module and pallet sections +Z facing Thermal Control Surfaces (TCS), and two typical gimballed scientific instruments having geometric acceptance angles of 10^o and 53^o (these acceptance angles were chosen to represent a typical ultraviolet system and the remote sensing platform respectively). The analysis was based upon the following assumptions:

a) all windows and scientific instrument primary mirrors are held at $T=20^oC$;

b) the Shuttle Orbiter remains in a -Z Local Vertical attitude with the velocity vector in a -X direction;

c) scientific instruments track an inertial target while in use; and

d) average beta angle = 60^{o}.

The results of this analysis are illustrated in Figure C-1 as a plot of the accumulated deposition as a function of mission day. Both return flux and line-of-sight deposition are included. The data presented in Figure C-1 is based on the assumption that the Spacelab windows are left uncovered continuously, the scientific instruments are continuously exposed, and tracking is in a modified local vertical attitude. For timelines differing from the above assumptions, accumulative deposition can be determined through summation of predicted deposition for each period of surface exposure.

The resulting degradation to the Mission 19a operational and optical surfaces based upon the worst case predicted deposition levels will be quite significant. This is summarized below.

Surface	Maximum Deposition (g/cm^2)	Estimated Degradation
Pallet TCS	8.0×10^{-5}	$\Delta\alpha_s$ white paint* =0.19
Module TCS	5.2×10^{-5}	$\Delta\alpha_s$ white paint* =0.16
+Z High Quality Window	4.7×10^{-4}	Transmission Loss to photopic eye = 52.0%
Aft Cone Viewing Window	3.4×10^{-4}	Transmission Loss to photopic eye = 42.0%
10^{o} Scientific Instrument	8.9×10^{-6}	Signal attenuation at 2500Å = 59%
53^{o} Scientific Instrument	2.3×10^{-4}	Signal attenuation at 2500Å = 100%

*$\Delta\alpha_s$ (i.e. the increase in solar absorptivity) is based upon S13G white thermal control coating degradation witnessed on Skylab for deposition of similar contaminant species under solar exposure. This is in addition to normal S13G degradation resulting from exposure to solar ultraviolet radiation.

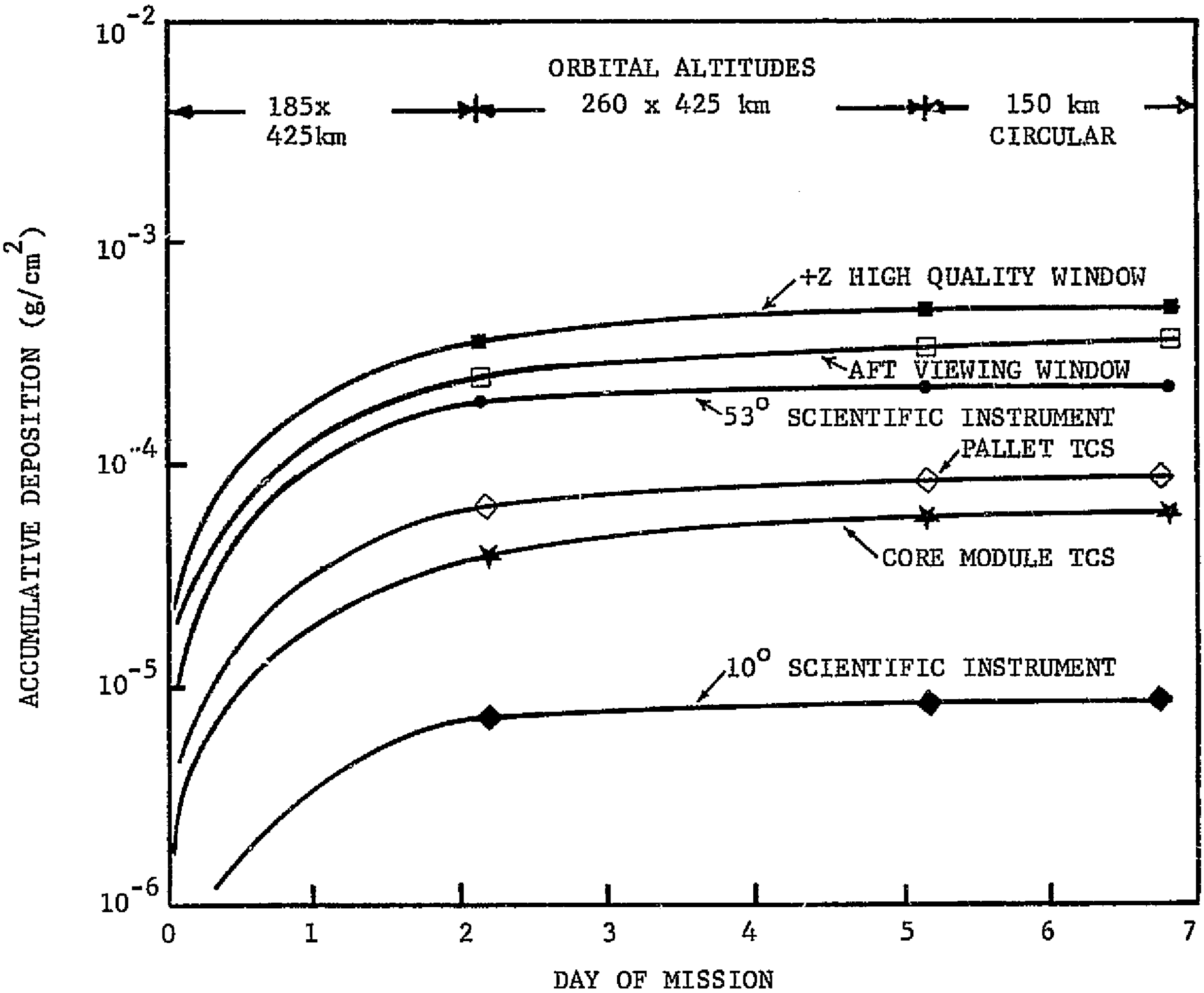

Figure C-1. Predicted Outgassing Deposition Levels for Selected Spacelab/AMPS Surfaces

Under the assumptions used for this analysis, a rather high risk potential of contamination degradation due to the deposition of outgassants has been identified. Because of this potential problem, further detailed analysis is required when final designs and timelines are established to refine and predict more accurately this risk potential to AMPS.

Since the major contaminant transport mechanism is the return flux of the outgassed molecules, the influence of orbital altitude upon the surface deposition rates is significant. The lower orbital altitudes being planned for AMPS enhances this contaminant potential greatly. Any future studies should consider: 1) effects of orbital altitude to identify a possible optimum orbital altitude from a contamination viewpoint as well as 2) higher resolution materials outgassing data for the major Spacelab nonmetallic materials such as the S13G white paint.

There are several considerations which can be implemented to minimize the potential of contamination degradation. This can be done through establishing proper operational procedures and timelining. Spacelab window covers should be closed at all times when the windows are not in use. The scientific instruments, especially those that are gimballed and detect in the ultraviolet wavelengths such as the remote sensing platform instruments, should be designed with contamination protective covers (as per the SSPD) that are opened only when data is being taken. If this proves impractical, the gimballed instruments should be caged in a +Z facing direction during instrument down time. Since a majority of the Mission 19a attitudes are a $\pm Z$ local vertical, this would minimize return flux to the critical optics. Degradation to the Spacelab thermal control surfaces can be minimized by avoiding solar exposure of the +Z side of the Shuttle Orbiter and Spacelab. This will not only decrease the outgassing rates of the major contributing surfaces, but also eliminate the photopolymerization of deposited outgassants. To decrease the ultimate impact of outgassing deposition upon the scientific instrument data, consideration should be given to timelining the operations of the most susceptible instruments (i.e. those detecting in the ultraviolet) early in the mission when deposition levels are less severe.

2.2.2 Shuttle Orbiter 25 lb and 900 lb Thrust Reaction Control System (RCS) Deposition - Approximately 393 lbs and 1410 lbs of fuel will be used by the 25 lb and 900 lb thrust RCS respectively during Mission 19a. The predicted deposition from these engines was determined based upon assumptions similar to those used in the outgassing analysis. Here, as with outgassing, direct line-of-sight deposition was determined to have negligible effects, while return flux of contaminants through interaction with the ambient atmosphere was assessed to be the most significant deposition mechanism. The following table depicts the predicted deposition levels on the selected Spacelab and scientific instrument surfaces for the Mission 19a mission profile.

Surface	25 lb RCS Deposition (g/cm^2)	900 lb RCS Deposition (g/cm^2)
Pallet TCS	$4.6x10^{-9}$	$8.1x10^{-7}$
Module TCS	$4.6x10^{-9}$	$8.1x10^{-7}$
+Z High Quality Window	$4.6x10^{-9}$	$8.1x10^{-7}$
Aft Cone Viewing Window	$3.2x10^{-10}$	$5.7x10^{-7}$
10^{o} Scientific Instrument	$6.5x10^{-11}$	$1.2x10^{-8}$
53^{o} Scientific Instrument	$1.7x10^{-9}$	$3.0x10^{-7}$

Contaminant sticking coefficient values were derived from MMH/N_2O_4 engine testing at Lewis Research Center and data acquired during the Skylab mission. The values presented are those anticipated after the sublimation period of the deposits has ended. The sublimation period is influenced by the exposure to ultraviolet radiation. The predicted values are weighed with ultraviolet exposure and represent worst case. However, on Skylab MMH/N_2O_4 engine deposits were not exposed to ultraviolet radiation and sublimated to 1/e of the original deposits in 72 hours. It is anticipated from the Mission 19a profile that those deposits will see some ultraviolet radiation.

The predicted deposition levels from these engines should have negligible impact on the Spacelab/scientific instrument critical surfaces.

2.2.3 <u>Orbital Maneuvering System (OMS) Deposition</u> - A total of three additional OMS firings are required during the course of the on orbit phase of Mission 19a in order to transfer the Shuttle Orbiter/Spacelab into varying desired orbits. The first of these firings will translate the vehicle from a 185 x 425 km orbit to a 260 x 425 km orbit using approximately 1469 lbs of fuel with the payload bay doors open. Deposition on the +Z facing Spacelab surfaces (i.e. windows and pallet/module TCS) will be approximately 2.4×10^{-9} g/cm^2 after resublimation of the initial deposit. The resulting impact should be negligible. The remaining two firing sequences present a somewhat different problem in that both are retro firings to decrease the orbital altitude. The first (approximately 5251 lbs of fuel) will change the previous orbit to 260 x 150 km, and the second (approximately 2119 lbs) will circularize the orbit at 150 km. These maneuvers require the engines to fire into the orbital drag vector creating a maximum return flux situation. Engine effluents will be swept across the Spacelab and scientific instrument surfaces depositing in varying degrees depending upon surface shadowing and temperature considerations. The following table depicts the anticipated deposition levels for the selected Spacelab/scientific instrument surfaces resulting from the two OMS retro burns assuming ultraviolet radiation of the deposits.

Surfaces	Deposition after Sublimation (g/cm^2)	Deposition after Sublimation (Å) $\rho = 1.0$ g/cm^3
Spacelab +Z Surfaces (Windows, & Pallet/Module TCS)	5.0×10^{-5}	5000
10° Scientific Instrument	2.0×10^{-7}	20
53° Scientific Instrument	5.4×10^{-6}	540

These deposition levels will cause an increase in solar absorptivity (α_s) of approximately 0.085 and a decrease in emissivity (ϵ) of approximately 0.18 for the S13G type pallet/module TCS as based upon Lewis Research Center test data. In addition, significant transmission/reflectance losses will be experienced by the exposed Spacelab windows and optical surfaces. If at all possible, based upon these results, consideration should be given to closing the payload bay doors during the retro firings of the OMS engines.

2.2.4 Induced Contaminant Environment - The induced contaminant environment consists of those molecular and particulate species emitted from the Shuttle Orbiter/Spacelab into the surrounding environment. These contaminants can cause degradation to desired AMPS scientific instrument data. The instruments most susceptible to degradation will be 1) those that must view through the induced cloud and 2) those that are attempting to study the ambient environment in the immediate vicinity of the spacecraft. To determine the thickness of the contaminant molecular cloud through which the scientific instruments must view, the contamination computer model was utilized in analyzing the major contaminant sources. These were outgassing, offgassing (i.e. the release of light gases, liquids, and volatiles) at 10 hours in the decay curve, cabin leakage, the 25 lb RCS, and the Shuttle Orbiter evaporator vents. Presented below are the predicted molecular number column densities (NCD) along a typical instrument line-of-sight extending out of the payload bay parallel to the Shuttle Orbiter +Z axis.

Contaminant Source	Total NCD (mol/cm^2)	Polar NCD (mol/cm^2)
Outgassing MAX*	9.9×10^{11}	9.9×10^{11}
MIN	7.4×10^{10}	7.4×10^{10}
Offgassing MAX	5.1×10^{13}	5.1×10^{13}
MIN	3.4×10^{12}	3.4×10^{12}
Cabin Leakage	2.4×10^{13}	5.0×10^{11}
25 lb RCS Aft -Z**	4.4×10^{14}	2.4×10^{14}
Aft ±Y	2.0×10^{14}	1.1×10^{14}
Fwd -Z	3.9×10^{12}	2.2×10^{12}
Evaporator	1.7×10^{14}	1.7×10^{14}

* MAX/MIN indicates the maximum and minimum temperature thermal profiles used in the analysis.

** Thruster

For other modeled viewing angles within a 100° cone above the payload bay centered around the +Z axis, the NCD will not vary more than an order of magnitude for any of the given sources. Of these sources, only outgassing and cabin leakage are uncontrollable or near quasi steady state. The 25 lb RCS is an intermittent source and could be inhibited thus eliminating its contribution to the NCD. This is also true of the evaporator vents which, depending on Shuttle Orbiter/Spacelab cooling and power requirements, can be inhibited for up to 12 hours if proper water storage facilities are supplied by the Payload. With time, offgassing will continue to decay from the 10 hour predictions depicted in the table until at 24 hours of vacuum exposure, the contribution of offgassing to the NCD should be small.

In addition to viewing through the molecular contaminants, the scientific instruments must also view through the induced particulate environment of the Shuttle Orbiter/Spacelab. The contaminant influence of the random emission of particles from the surfaces of the Shuttle Orbiter and Spacelab can be qualitatively assessed from observations made by the Skylab white light coronagraph. This data indicated that Skylab demonstrated a quasi steady state emission rate of approximately 60 particles/second greater than 10 to 25 microns (4.78 particles/steradian/second). Since Skylab and the Shuttle Orbiter/Spacelab configurations have essentially equal surface areas (approximately 13,000 ft^2), this rate was assumed for the Mission 19a analysis. However, due to reusability of the Spacelab/Shuttle Orbiter and the numerous gimballed systems being used, the rate could be considerably higher. In as much as current criteria limits this rate to approximately 547 particles/second greater than 10 microns, the rate deduced from Skylab is well within this tolerance. Although a detailed analysis of the AMPS scientific instruments was not possible with the available sensitivity data, the impact of particles on scientific data is expected to be small. False star tracking by the Shuttle Orbiter star trackers as experienced on Skylab could create pointing problems for scientific instruments. This can be reduced appreciably by decreasing star tracker sensitivity thresholds to acquisition of only bright target stars and by limiting the frequency of star reference updating.

In summary, for those instruments that must view through the induced molecular and particulate environment the contamination control criteria will be satisfied for particles and exceeded for molecular NCD. Under the conditions stated and the modeling assumptions used, the NCD criteria of 10^{12} polar molecules/cm^2 maximum allowable stated in JSC 07700[1] is approached or exceeded by each source individually. Proper timelining of sensitive instrument operations until offgassing has ceased and inhibiting of the 25 lb RCS and the evaporator vents would decrease the total NCD significantly. However, the criteria will still be exceeded slightly during maximum temperature portions of an orbit by the sum of outgassing and cabin leakage. The need for these measures is somewhat in question at this time because the nature and objectives of the Mission 19a scientific instruments (i.e. target objectives and wavelengths of interest) indicate that the impact of NCD levels predicted should be small. Inflight contamination control criteria stated in the SSPD[2] indicates the control required for each scientific instrument is $\leq 10^{12}$ molecules/cm^2 (i.e. NCD $> 10^{12}$ molecules/cm^2 will be acceptable). Until designs and sensitivities of the AMPS instruments are more firmly established, how much greater than 10^{12} molecules/cm^2 that can be tolerated can only be approximated. However, an NCD approaching 10^{12} molecules/cm^2 can be achieved through the proper timelining of operations and inhibiting of sources if final sensitivities dictate this.

For those scientific instruments attempting to study the ambient environment, the greatest concern is the perturbation of the ambient environment by the emitted contaminant species. The basic impact will be to modify the ambient atmosphere measurements to be made by the ion probes and mass spectrometers. To illustrate this potential, the return flux flowing through a cylindrical type probe positioned at a location one meter above the Shuttle Orbiter skinline at X_o = 1158 parallel to the velocity vector was determined for the projected AMPS altitudes. The resulting predictions and corresponding ambient fluxes by constituent are compared in Table C-I for three altitudes encompassing the anticipated extremes. The sources considered were limited to the light gases that might be expected in the ambient at the altitudes analyzed.

(1) JSC 07700 Volume XIV, Revision C. "Space Shuttle Program Space Shuttle System Payload System Payload Accommodations," July 3, 1974, Lyndon B. Johnson Space Center.

(2) "Summarized NASA Payload Descriptions - Sortie Payloads," Level B Data, July 1974, George C. Marshall Space Flight Center.

Table C-1. AMPS Ambient Atmosphere Probe Flux Predictions

ALTITUDE / Specie	150 km		185 km		425 km	
	Contaminant Flux (mol/cm^2/sec)	Ambient[6] Flux (mol/cm^2/sec)	Contaminant Flux (mol/cm^2/sec)	Ambient[6] Flux (mol/cm^2/sec)	Contaminant Flux (mol/cm^2/sec)	Ambient[6] Flux (mol/cm^2/sec)
CO	1.9×10^{14}		6.3×10^{13}		8.1×10^{11}	
CO_2	3.3×10^{14}		1.1×10^{14}		9.4×10^{11}	
H	5.0×10^{14}	3.2×10^{11}	1.7×10^{14}	1.2×10^{11}	2.1×10^{12}	1.7×10^{10}
H_2	3.3×10^{15}		1.1×10^{15}		1.4×10^{13}	
H_2O	2.3×10^{15}		7.7×10^{14}		6.9×10^{12}	
NO	8.[illegible]x10^{11}		2.9×10^{11}		3.6×10^{9}	
N_2	1.8×10^{15}	7.5×10^{15}	6.0×10^{14}	3.8×10^{15}	6.3×10^{12}	1.5×10^{13}
O	8.1×10^{11}	7.1×10^{15}	2.7×10^{11}	2.4×10^{15}	3.4×10^{9}	1.1×10^{14}
OH	1.5×10^{13}		5.0×10^{12}		6.2×10^{10}	
O_2	4.0×10^{14}	2.1×10^{15}	1.3×10^{14}	3.1×10^{14}	1.4×10^{12}	7.7×10^{11}
A	1.8×10^{13}	7.6×10^{13}	6.0×10^{12}	7.6×10^{12}	4.4×10^{10}	1.9×10^{9}
He	0	2.6×10^{12}	0	1.6×10^{12}	0	7.7×10^{11}

(6) Johnson, F. S.: "Satellite Environment Handbook," Stanford University Press, Stanford, California, 1965.

In some cases, the flux of contaminant species approaches or exceeds that of the ambient flux. Of these, the H flux can be minimized by constraining the 25 lb RCS during data acquisition and the flux of A can be diminished by allowing offgassing to decay to an acceptable level after launch (approximately 24 hours) before measurements are attempted. The O_2 and N_2 from cabin leakage will be difficult to control. In addition, the N_2 and He required for cooling the AMPS cryogenic infrared detectors will boil off and affect the ambient measurements. These boil off sources were not included in Table C-I but should be analyzed in detail for their additional impact.

Figures C-2 and C-3 present this information graphically for the worst case and least case contaminant fluxes respectively in order to illustrate the safe distances from the Shuttle Orbiter at the three analyzed altitudes where ambient atmosphere measurements might be made. The data presented is in the form of molecular flux (both contaminant and ambient) to the representative molecular probe having a π steradian acceptance angle as a function of distance from the Shuttle Orbiter skinline along the +Z axis. Figure C-2 depicts the worst case contaminant flux considering the presence of the following light gas sources: 1) offgassing at the 10 hour point in the decay curve; 2) Spacelab/Shuttle Orbiter cabin atmosphere leakage; 3) Shuttle Orbiter evaporator vent; and 4) the 25 lb RCS thrusters. Both the total ambient flux and the ambient flux excluding atomic oxygen are presented. This was done to allow for closer comparison between the ambient and contaminant species since negligible atomic oxygen will exist in the contaminant flux. The results indicate that at all altitudes analyzed, the worst case contaminant flux exceeds the ambient flux (excluding atomic oxygen) at certain distances from the Shuttle Orbiter. The following table indicates the distances from the Shuttle Orbiter where the maximum contaminant flux will be less than 10% of the equivalent ambient.

Altitude	10% Distance
150 km	90 meters
185 km	80 meters
425 km	180 meters

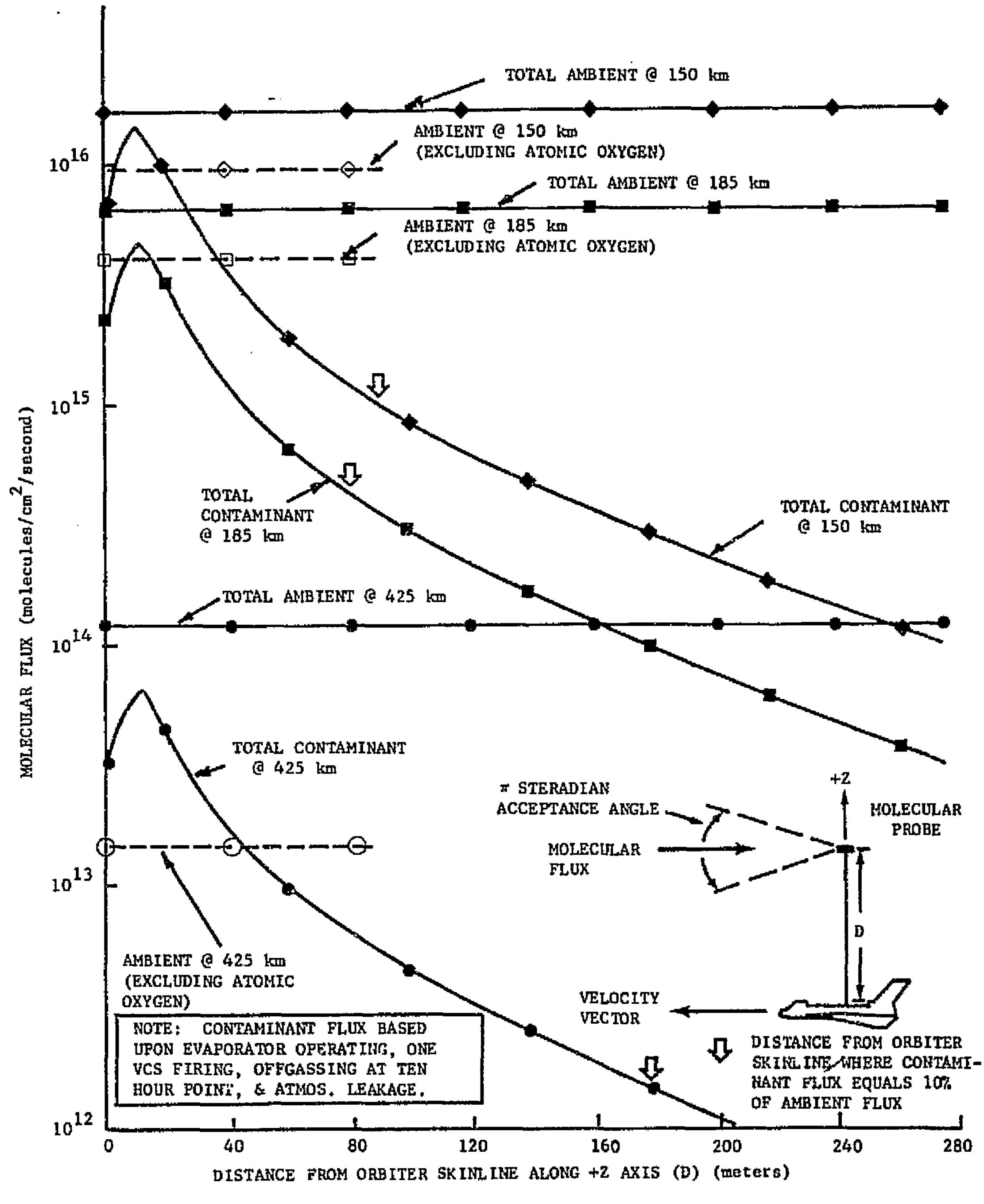

Figure C-2. Worst Case Molecular Flux as a Function of Distance from the Shuttle Orbiter Skinline Along the +Z Axis

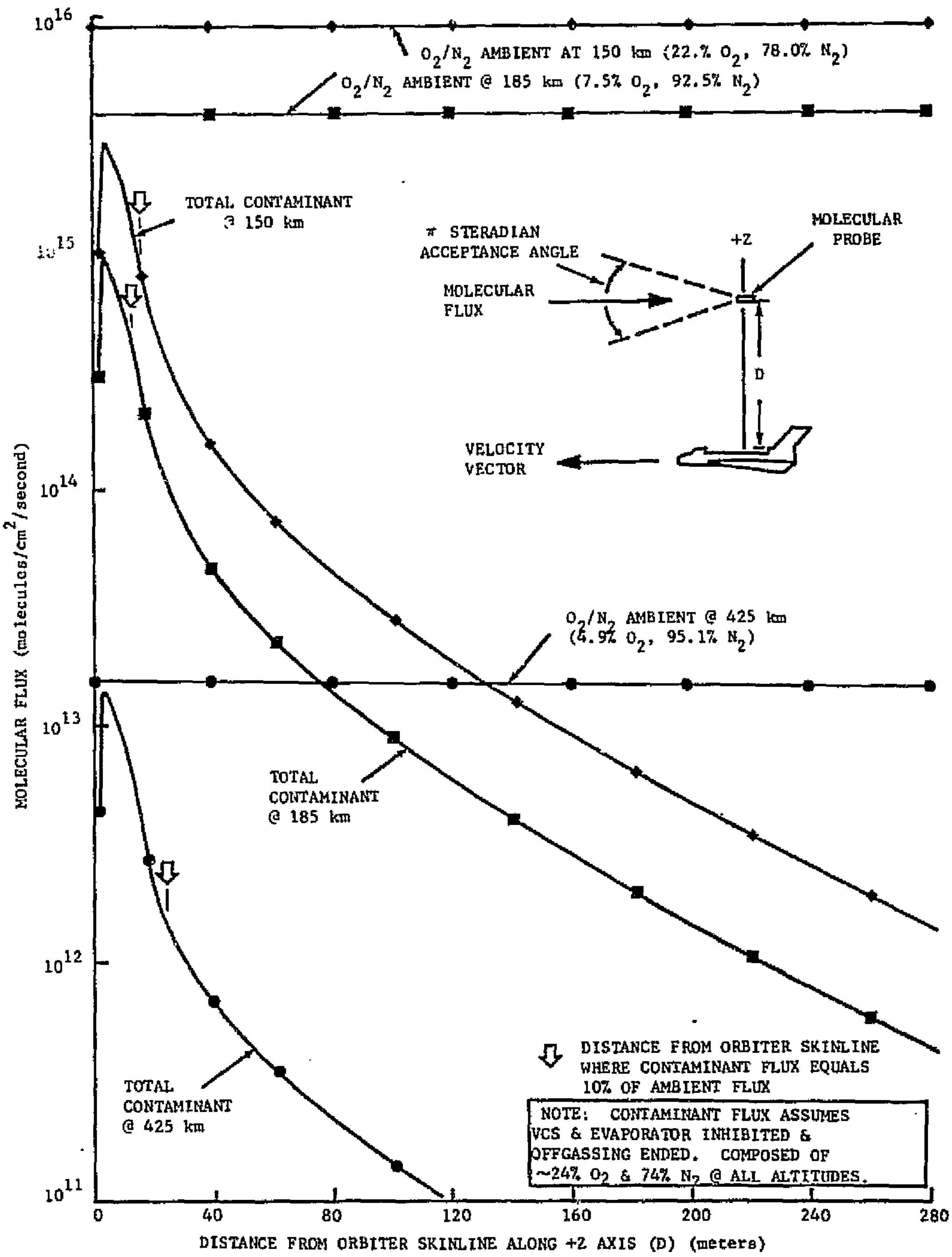

Figure C-3. Least Case Molecular Flux as a Function of Distance from the Shuttle Orbiter Skinline Along the +Z Axis

Figure C-3 presents a comparison of the minimum contaminant flux (assuming the evaporator and 25 lb RCS are inhibited and offgassing has decayed to a negligible level) with the O_2/N_2 component of the ambient flux. The corresponding distances from the Shuttle Orbiter where the minimum contaminant flux will be less than 10% of the O_2/N_2 ambient will be:

Altitude	10% Distance
150 km	15 meters
185 km	12 meters
425 km	22 meters

Indications are at the lower altitudes that the 10% point can be achieved at a distance in the 1 to 2 meter range. This can be misleading without considering the comparison of individual specie percentages at the various altitudes. In addition, the contributions from direct line-of-sight impingement into the molecular probe were not considered in the predictions. At localized positions near the Shuttle Orbiter/Spacelab contaminant sources, the contaminant flux could be significantly higher. Therefore, the results of this analysis would tend to indicate that the ambient flux measurements should be attempted through the use of subsatellite or extendable boom mounted scientific probes properly timelined to avoid high offgassing with the 25 lb RCS and evaporator inhibited.

Materials offgassing during the first few orbits of the mission may induce pressures high enough to create the potential of corona arc-over at high voltage power supplies. In specific corona susceptible areas, realtime ion pressure gages should be installed to monitor pressure decay to allow the safe timelining of high voltage system activations such as the Lidar laser system and the ion and electron accelerators.

2.2.5 Other On Orbit Considerations - During the on orbit portions of the mission, operation of several of the AMPS scientific instruments will result in situations which might compromise the contamination control of the Mission 19a Spacelab/scientific instruments. These operations include subsatellite deployment/retrieval and free flying operations, ion and electron

accelerator operations, and barium canister deployment. Contamination considerations for these operations are briefly summarized below.

2.2.5.1 Subsatellite - The deployment scheme of the subsatellite initially involves its release from the Spacelab pallet and placement above the payload bay by use of the Shuttle Orbiter manipulator. The subsatellite hydrazine monopropellant thrusters are then fired to place it into a parking orbit 20 to 50 meters above the Shuttle Orbiter. Hydrazine engines are fairly clean in that the primary effluents are H_2, N_2 and NH_3. However, depending upon the hydrazine catalyst bed design, particulate matter can be eroded from the bed during thruster firings. This is especially true during initial firings when the catalyst granules still have relatively sharp edges. Entrained in the thruster gases, these particles could pit and erode Spacelab surfaces on which they impinge. This impact is expected to be small, but thrusting in the direction of the payload bay should be avoided.

The subsatellite will remain in the parking orbit for up to 3 days during which it will receive direct impingement from Shuttle Orbiter/Spacelab contaminant sources. Assuming an average separation distance above the payload bay of 30 meters, the subsatellite exterior will receive a deposition of approximately 5.6×10^{-6} g/cm^2 from outgassing, 2.6×10^{-6} g/cm^2 from the 900 lb RCS engines, and a negligible amount from the 25 lb RCS engines. Assuming that the ultraviolet detector of the subsatellite has a 10° acceptance angle and that it views the Shuttle Orbiter continuously for 3 days (extreme worst case), approximately 18Å would deposit resulting in approximately 1% loss of transmission at 2500Å. This is tolerable for Mission 19a but should be reviewed for ensuing missions reusing this instrument.

Retrieval of the subsatellite will be by means of the hydrazine thrusters and the Shuttle Orbiter manipulator. However, the Shuttle Orbiter RCS thrusters may be required for final positioning. If this is necessary, RCS engine impingement on the subsatellite should be avoided through establishing proper rendezvous procedures.

2.2.5.2 Ion and Electron Accelerators - During operation of the ion and electron accelerators, a high electrostatic charge will accumulate on the Shuttle Orbiter/Spacelab vehicle. Discharge of this charge will be difficult due to the extensive use of dielectric surface coatings.

Contaminant deposition may be significantly enhanced by the accumulative electrostatic charge. This phenomena may result in higher than anticipated deposition levels during accelerator operation in addition to other potential problems. These will include protective coating perforations and the possibility of changing the ion and electron accelerator performance due to the voltage potential difference decrease between the Shuttle Orbiter/Spacelab and the instruments. A detailed analysis of this phenomena is required to quantitatively assess the final impacts.

2.2.5.3 Barium Canister - Although the contaminant impact may be small, the potential re-encounter of the ejected barium and sulfur hexafluoride cloud should be investigated. Ejection will be into a low earth parking orbit through which the Shuttle Orbiter/Spacelab may pass later in the mission. Relative trajectory and dispersion analysis on the resulting cloud and final impact assessment is required. The resulting cloud could interfere with critical Shuttle Orbiter/Spacelab operational surfaces and the scientific instruments attempting to view through it. This may necessitate additional timelining, viewing constraints, or changing the orbital relationships between the Shuttle Orbiter/Spacelab and the barium canister.

2.3 Deorbit Through Landing Contamination - Prior to the two required OMS firings for deorbit transfer, the payload bay doors will be closed and latched. The first of the OMS firings (1549 lbs of fuel) will be used to increase the orbital velocity approximately 24 meters/second and the second (2715 lbs) will be a retro thrust. Only a small amount of the OMS effluents will be able to enter the active payload bay vents. However, to eliminate the potential of any further spacelab degradation, consideration should be given to close the vents during these maneuvers. In addition, the cryogenic He and N_2 supply flow to the infrared detectors should be curtailed prior to the 12 hour "toasting" period to allow the systems to thermally stabilize and prevent excessive condensation of condensible contaminants ingested during reentry. All contamination protective

covers and aperture doors should be in a closed position prior to deorbit. Once deorbit has been initiated, the active vents must be reopened and remain opened until just prior to the blackout period which starts at approximately 400,000 feet elevation. During this period aerodynamic heating and erosion of the hotter surfaces will cause a hot molecular and particulate plasma sheath to envelope the Shuttle Orbiter. The closed active vents will prevent ingestion of this material into the payload bay. However, the inner surfaces of the outer skin and the outer layers of insulation will become hot and outgassing products from these materials can condense on the cooler surfaces of the Mission 19a hardware. The hot plasma from the outer surfaces can enter passive vents which will be open continuously. The passively vented areas, therefore, become a possible contamination source for subsequent missions and consideration should be given to monitor and provide the necessary clean up of these areas depending upon the observed contamination.

When the active payload bay vents are opened at 70,000 ft altitude, the external surfaces will still be quite hot and will be smoking and outgassing although to a much lesser degree than during the blackout period. The payload bay pressure will be approximately 0.8 psi below the external ambient pressure and some of the contaminant products from the external surfaces will be forced into the bay to condense on the much cooler internal surfaces. However, the payload bay vents must be opened at this time to reduce pressure stresses. During the remainder of the time until shortly after touchdown, the payload bay pressure will remain below the external pressure so that any contaminants generated externally or already existent in the external atmosphere (such as sand, dust, salt, fog, and smog) will be continuously forced into the open vents. Ingestion of particulate matter will be limited significantly by the 35 micron filters in the active vent system. Upon touchdown, erosion products from the landing strip surface and from the Shuttle Orbiter tires could be forced into the vents, although the Shuttle Orbiter lower body and wings will provide a good shield against such action. Closing of the active vents during the last few hundred meters of descent until the ground purge is initiated would minimize further ingestion.

During the 30 minute cooldown period, heat from the external surfaces will continue to soak into the interior so that the inner bay liner surfaces may reach temperatures as high as 200°F with temperatures progressively higher through the insulation toward the outer surface. The Spacelab and scientific instrument surfaces will remain cooler so that outgassing products from the interior surfaces will continue to condense on them. When the cool gas purge is started, 30 minutes after touchdown, outgassing condensation will be greatly reduced and eventually stopped. The purge over-pressure will force most of the outgassing products out through the vents and, by cooling the hot materials, reduce the outgassing to a very low level.

It may be contended that contamination occurring during the reentry, landing, and post landing period is of no consequence because the Spacelab/instruments have completed their mission and can be cleaned before reuse. However, investigators may be interested in maintaining on orbit condition cleanliness of their experiments as a calibration check and contamination occurring after the orbit period would invalidate such a check. Also, contaminants can get into locations where they may not be noticed or from which they cannot be removed. They could then migrate to more sensitive areas during later missions. It is quite possible that contamination of the Spacelab and instruments during reentry would require considerable refurbishing for the next mission.

The exact level of predicted degradation created during reentry is currently unknown. Data acquired from the inflight contamination monitors of the earlier Spacelab missions and observed degradation of the preceding Spacelab/scientific instrument missions may dictate tighter control measures to be instituted. Extensive protective devices such as a module/pallet contamination abatement blanket or a purge supply for payload bay repressurization during reentry may be required. These approaches might seem extreme, but in the final analysis their cost effectiveness may be demonstrated when compared with the accumulative refurbishment costs for the numerous Spacelab missions.

2.4 Summary - The results of these analyses indicate several areas of concern related to the contaminant impacts anticipated during the launch, on orbit, and reentry phases of

Mission 19a. The major items are summarized below for each mission phase along with recommendations to minimize the impacts.

2.4.1 Launch - Contamination during the launch phase while the payload bay doors are closed should be small if the active vents are closed during SRB separation. Particulate and molecular deposits resulting from ground operations, SRB separation motors, and aerodynamic heating may migrate during later mission phases and impact the Mission 19a Spacelab and scientific instruments. To what degree this will happen is currently unknown. During the orbital insertion burns of the OMS engines, backflow effluents can deposit upon and degrade sensitive surfaces in the payload bay with the doors open. It is, therefore, recommended that the payload bay doors be closed during these maneuvers.

2.4.2 On Orbit - Significant deposition will result on Spacelab/scientific instrument surfaces from the outgassing of Shuttle Orbiter/Spacelab nonmetallic materials under the assumptions used in this study. This deposition will increase the solar absorptivity of the Spacelab white thermal control surfaces and decrease both the transmission of Spacelab windows and the reflectance/transmission of scientific instrument optics appreciably. This is especially true for those instruments detecting in the ultraviolet wavelengths. This degradation can be minimized by 1) closing window covers and optical instrument covers during non-use periods; 2) caging optical instruments in a +Z direction when not in use to minimize return flux; 3) avoiding solar exposure of the +Z side of the Shuttle Orbiter and Spacelab; and 4) timelining the operations of the most sensitive scientific instruments for the earlier portions of the mission when degradation will be at a lower level. Deposition of the effluents from the 25 lb and 900 lb RCS engines upon the Spacelab and scientific instruments in the payload bay should result in minimal degradation to critical surfaces. However, deposition resulting from the required on orbit OMS maneuvers (especially the retro burns) will induce considerable degradation to Mission 19a susceptible surfaces. It is, therefore, strongly recommended that the payload bay doors be closed during all on orbit OMS firings.

The induced contaminant environment may impact both those instruments attempting to view through it and those attempting to study the ambient atmosphere. The predicted thickness or molecular number column density through which the instruments must view approaches or exceeds the stated criteria of 10^{12} polar molecules/cm^2 for most sources. In addition, the flux of some contaminant species approaches or exceeds the flux of the same molecular species that the ion probes and mass spectrometers are attempting to measure in the ambient atmosphere. The impacts from this type of contamination can be decreased by inhibiting RCS firings during data acquisition and by timelining data takes after the initial high weight loss period of nonmetallic material offgassing (24 hours) has subsided. Species resulting from cabin leakage (O_2/N_2) will be difficult to control and may degrade the desired data from these AMPS instruments. In addition, cryogenic He and N_2 gas boil-off from the cooled infrared instruments may degrade the ambient atmospheric measurements and should be analyzed in detail for proper timelining and boil-off vent locations. Pressures resulting from the induced molecular environment can induce corona arc-over at high voltage power supplies. Because of this, pressures should be monitored in these areas and time should be allowed for the high offgassing period to subside before these systems are activated. Also the induced particulate environment was analyzed and determined to have minimal impact to the Mission 19a scientific instruments if proper star tracker reference updating procedures are followed.

Other areas of concern include the subsatellite, the ion and electron accelerators, and the barium/sulfur hexafluoride canister. The subsatellite hydrazine thrusters will be relatively clean, but may erode hardware surfaces on which they impinge through the entrainment of catalyst bed particulates in the plume. Firing in the direction of the Shuttle Orbiter/Spacelab should be avoided. While in its parking orbit above the Shuttle Orbiter bay, deposition from the Shuttle Orbiter/Spacelab sources should have only minor effects upon the subsatellite. However, significant deposition can occur during retrieval operations if the 900 lb RCS thrusters are allowed to impinge upon the subsatellite. Appropriate rendezvous maneuvers should be devised to avoid this. Operation of the ion and electron accelerators will induce an electrostatic charge

build-up on the Shuttle Orbiter/Spacelab surfaces which may enhance the ability of an impinging contaminant to stick. In addition, the barium and sulfur hexafluoride cloud may impact the Shuttle Orbiter/Spacelab surfaces and interfere with those instruments attempting to view through it. Both of these phenomena require further detailed analysis.

2.4.3 Reentry - Effluents from the OMS firings required to initiate deorbit may enter the active payload bay vents and further degrade sensitive surfaces. These vents should be closed during the firings to avoid this. Of prime concern is the ingestion and subsequent condensation of hot molecular contaminants within the payload bay resulting from aerodynamic heating during reentry. The subsequent heat soaking into internal payload bay surfaces will increase the outgassing rates of these surfaces. The impacts from this reentry contaminant environment are currently unknown. However, based upon degradation experienced on earlier Spacelab missions, protective covers or purge/pressurization systems may be required to minimize the necessary ground refurbishment operations. All contamination control scientific instrument covers should be in place during reentry operations.

APPENDIX D

Mission 12 - Life Sciences Shuttle Laboratory

Contamination Assessment

D-1

CONTENTS

MISSION 12 CONTAMINATION ASSESSMENT

1. INTRODUCTION

This appendix establishes the contamination impact analysis conducted for the Mission 12 Spacelab Life Sciences Shuttle Laboratory mission. The impact of the contaminant environment upon this mission will basically be limited to degradation of externally exposed Spacelab surfaces as well as those of the Department of Defense (DOD), Space Test Program Experiment tellite (SEXSAT), and the Teleoperator Orbiter Bay Experiment (TOBE). This is due to the fact that the scientific objectives of this mission do not involve the requirement to obtain scientific data which would necessitate viewing through the molecular or particulate environment of the Spacelab/Shuttle Orbiter vehicle. For the purposes of this analysis, it has been assumed that the Spacelab hardware (i.e. module, platform, tunnel structures, etc.) has been completely refurbished from previous flights and is in "first launch" condition prior to the Mission 12 flight. The basis for this analysis was the combined Spacelab/Shuttle Orbiter contamination computer model, previous ground test and flight data, and published contamination control criteria included in JSC 07700[1] and the SSPD[2].

The main objective of the contamination control for this Spacelab mission is to insure that the accumulative impact of deposition from the induced environment upon Spacelab and payload sensitive surfaces is such as to insure the success of the ongoing mission as well as ensuing missions which require the reuse of the Mission 12 hardware. If controls are inadequate, extensive ground refurbishment will be required on the reusable hardware. In general, this hardware will be only susceptible to the deposition of contaminant effluents on critical surfaces (e.g. thermal control surfaces, windows, and exposed optical surfaces of SEXSAT and TOBE).

(1) JSC 07700, Vol. XIV, Revision C, "Space Shuttle Program Space Shuttle Payload Accommodations," July 3, 1974, Lyndon B. Johnson Space Center.

(2) "Summarized NASA Payload Descriptions - Sortie Payloads," Level B Data, July 1974, George C. Marshall Space Flight Center.

2.0 STUDY RESULTS

2.1 Launch Through Orbital Insertion Contamination - Throughout the launch phase of Mission 12 several operations will occur which may create possible high risk potentials of contamination of the Spacelab/scientific instrument sensitive surfaces within the payload bay of the Shuttle Orbiter. These include the contamination potentials resulting from 1) ingestion of contaminants into the active vents; 2) Solid Rocket Booster (SRB) separation rocket exhausts; and 3) Orbital Maneuvering System (OMS) engine firings for final orbital insertion. These are covered in the following paragraphs.

Attitude maneuvers during the high dynamic pressure regime incurred during launch will create enough pressure variation across the active vents to allow the external environment to be ingested into one vent and flow out of another presenting a potential contamination problem. Launch vibrations and the aerodynamic heating that occurs during the maximum dynamic pressure regime will cause the release of contaminants from the external Shuttle Orbiter and launch vehicle surfaces that are capable of being ingested into the bay. The 35 micron filtered active vents should preclude the ingestion of most of the larger particulate matter. However, particulate matter that may be released from within the bay during launch will migrate under the influence of gravity and inertia in the aft direction and potentially deposit on exposed sensitive surfaces. This should be a short term phenomena. Although the impact should be negligible to the Spacelab critical surfaces, the sensitive SEXSAT and TOBE scientific instruments may require additional protection. One concept of the SEXSAT includes an ultraviolet TV system (1000Å - 2000Å) and spectrophotometers (170Å - 1600Å) which will be extremely susceptible to degradation from thin film and particulate deposition. The TOBE design includes a visible TV system for operator observation during remote operations which will also be susceptible to contamination. These systems should all have contaminant protective covers incorporated into their designs which should be held in a closed position throughout all launch/orbital insertion operations.

SRB separation will be accomplished by small retro rockets which can develop pressures on the external Shuttle Orbiter surfaces as high as 5 psi. During this operation, it is recommended that the active payload bay vents be closed to preclude the ingestion of exhaust effluents into the bay. Exhaust products will be able to enter the passively vented Shuttle Orbiter cavities and may deposit on external surfaces to be re-emitted later in the mission.

After main engine cut off, the external tank will be released and the OMS will be fired for approximately 153 seconds consuming 6294 lbs of fuel to insert the Shuttle Orbiter into a 109x370 km elliptical orbit. During the ensuing OMS firing for orbit circularization at 370 km, the payload bay doors are scheduled to remain closed as stated in the study guidelines, therefore, negligible degradation should result.

2.2 <u>On Orbit Contamination</u> - Once the Mission 12 Spacelab/Shuttle Orbiter has achieved orbit, several additional contamination sources and phenomena must be considered. These include, but may not be limited to, the following major items that have been identified to date:

a) outgassing deposition from the vacuum exposed nonmetallic surfaces of the Shuttle Orbiter/Spacelab;

b) Shuttle Orbiter 25 lb and 900 lb thrust Reaction Control System (RCS) engine exhaust effluent deposition; and

c) other on orbit contamination considerations including the SEXSAT and the TOBE.

The analyses of these are discussed in the following subsections. Additional known sources which have not been mentioned are felt to have only second order effects based upon the relative magnitudes of anticipated flux rates or due to the fact that the contaminant species are not expected to stick to sensitive surfaces at their estimated temperatures.

2.2.1 <u>Outgassing Deposition</u> - There are two basic mechanisms by which outgassed species may be transported between surfaces. These are direct line-of-sight and return flux resulting

from interactions with the ambient atmosphere. Both mechanisms were investigated for their potential impacts to the operational surfaces of Mission 12 through use of the contamination computer model. Direct line-of-sight deposition between the Spacelab and Shuttle Orbiter surfaces was found to be negligible due to the limited number of surfaces within a direct line-of-sight of the Spacelab surfaces and their similarities of thermal profiles.

For the anticipated mission profile and configuration of Mission 12, the primary deposition mechanism will be the result of return flux of the outgassed contaminants. Selected Spacelab surfaces were chosen for analysis in an attempt to encompass the majority of anticipated deposition levels. These included the +Z facing Spacelab module windows, the Spacelab aft conical section window, and the core module +Z facing Thermal Control Surface (TCS). The analysis was based upon the assumptions that all windows are held at $T=20^{\circ}C$ and the Shuttle Orbiter remains in a stable gravity gradient attitude with the Y axis parallel to the velocity vector.

The results of this analysis indicate that the +Z facing Spacelab TCS will receive approximately 7.6×10^{-6} g/cm^2 of deposited outgassants which equates to an increase in solar absorptivity of 0.05 based upon S13G white thermal control coating degradation witnessed on Skylab for deposition of similar contaminant species under solar exposure. Indications are that this will have little impact on Spacelab thermal control although the resulting discoloration may be undesirable from an aesthetic viewpoint. However, this level may impact the TOBE and SEXSAT thermal control, but to what degree is yet to be determined. For this mission the window covers will only be opened for occasional crew viewing and consequently negligible degradation will occur, although the windows will accumulate deposition at an average rate of 7Å per orbit while they are open. Degradation to the Spacelab, TOBE, and SEXSAT TCS can be minimized by avoiding solar exposure of the +Z side of the Shuttle Orbiter and Spacelab. This will not only decrease the outgassing rates of the major contributing surfaces, but also eliminate the photopolymerization of deposited outgassants.

In addition, even though the specific geometry of the SEXSAT satellite was not modeled, the potential degradation to its solar array system should be discussed. The possibility exists (depending upon the solar array system final design, spectral response, and the geometric relationships of this system with the forward cone of the Spacelab) that significant degradation could be induced from line-of-sight outgassing deposition as well as return flux from the entire vehicle during the 140 plus hours that the SEXSAT is scheduled to remain in the payload bay after launch. Further investigation of this is a definite requirement. However, to preclude this potential degradation, consideration should be given to earlier deployment of the SEXSAT or, if this proves not to be feasible, the contamination protective covers suggested for the launch phase could be enlarged to allow for total encapsulation of the SEXSAT up to the time of activation.

The TOBE employs an occulting video camera system which could experience similar degradation if left exposed to the contaminant environment within the payload bay. Therefore, the optical surfaces of the video system should be protected when not in use.

2.2.2 Shuttle Orbiter 25 lb and 900 lb Thrust Reaction Control System Deposition - Due to the fact that the Mission 12 Spacelab/Shuttle Orbiter vehicle will fly primarily in a stable gravity gradient attitude, there is currently no requirement for usage of the 25 lb thrust RCS engines and consequently no deposition will result. There is, however, a requirement to utilize the 900 lb RCS engines for attitude maneuvers and SEXSAT deployment consuming approximately 547 lbs of fuel total. Here, as with outgassing, direct line-of-sight deposition was determined to have negligible effects, while return flux of contaminants through interaction with the ambient atmosphere was assessed to be the most significant deposition mechanism. For exposed +Z facing surfaces within the payload bay, a deposit of approximately 2×10^{-8} g/cm^2 (2Å) will result from the use of these engines based upon sticking coefficient data derived from MMH/N_2O_4 engine testing at Lewis Research Center and data acquired during the Skylab missions. The amount deposited should present no problem for Mission 12.

2.2.3 Other On Orbit Considerations - During the on orbit portions of this mission, operation of several of the Mission 12 instruments will result in situations which might compromise the contamination control of Spacelab or instrument sensitive surfaces. These operations include the deployment of the SEXSAT DOD satellite and checkout of the TOBE. In addition, the potential of corona arc-over at high voltage power supplies of the payload bay instruments must be considered. Contamination considerations for these items are briefly summarized below.

2.2.3.1 SEXSAT DOD Satellite -The SEXSAT vehicle currently plans to employ two TE-M-458 solid rocket motors to deploy it from the Shuttle Orbiter bay into a high-apogee eccentric orbit. Solid engine exhaust products can be extremely detrimental to surfaces upon which their effluents impinge. The design and thrust levels of these engines is currently unknown. However, characteristically solid engine exhausts can create erosion or abrasion of sensitive surfaces as well as induce significant levels of deposition. A deployment scheme utilizing the remote manipulator system and either the SEXSAT hydrazine thrusters or the Shuttle Orbiter RCS (avoiding SEXSAT impingement) should be devised to insure an adequate separation distance before the solid rockets are fired.

2.2.3.2 Teleoperator Orbiter Bay Experiment - The TOBE system employs numerous telegraphing and movable actuator arms which will require extensive lubrication to insure proper operation. Due to the many diverse potential operational locations of the TOBE, precautions must be taken in the design to minimize particulate or molecular contamination resulting from the type of lubrication used (dry or wet) as well as other forms of contamination such as TOBE materials outgassing. Proper encapsulation and/or materials selection will be necessary. This will be even more critical during free flying missions when the teleoperator is working near contaminant sensitive surfaces such as scientific instrument optics.

For the relatively short time the TOBE is scheduled for above-the-bay operation during Mission 12 (approximately 4 hours), direct line-of-sight impingement deposition from Spacelab/Shuttle Orbiter sources will be negligible assuming limited RCS

usage (approximately $3x10^{-7}$ g/cm^2 (30Å) at 15 meters above the Shuttle Orbiter). However, significant increases in operational time could result in degradation to the TOBE TV system and thermal control surfaces.

2.2.3.3 <u>Corona</u> - The high voltage power supplies of the SEXSAT and TOBE (especially the TV systems) may be susceptible to corona arc-over during periods of high localized or general offgassing. It is, therefore, recommended that activation of these systems be delayed until the high offgassing period has ceased and that consideration be given to incorporating ion pressure gages or pressure switches as used on the Skylab vidicon TV system to prevent system damage.

2.3 <u>Deorbit Through Landing Contamination</u> - During the reentry and landing phase of Mission 12 the Spacelab and TOBE will be exposed to significant levels of potential contamination. Included in these will be OMS effluent ingestion at deorbit initiation, ingestion of hot gases and particles ($\leq$ 35 microns) from the reentry plasma sheath, atmospheric humidity, dust, etc., landing strip generated contamination, and materials outgassing prior to ground purge initiation. The exact level of predicted degradation created during reentry is currently unknown. Data acquired from the inflight contamination monitors of the ealier Spacelab missions and observed degradation of the preceding Spacelab/scientific instrument missions may dictate tight control measures to be instituted. In any event, it is recommended that the TOBE protective cover be replaced prior to deorbit initiation to minimize required ground refurbishment of this instrument.

2.4 <u>Summary</u> - The results of these analyses indicated several areas of concern related to the contaminant impacts anticipated during the various phases of Mission 12. The major items are summarized below along with recommendations to minimize the impacts.

Deposition resulting from the return flux of outgassing nonmetallic materials will increase the solar absortivity of white Spacelab, TOBE, and SEXSAT thermal control surfaces by as much as 0.05. No appreciable effect is anticipated for the Spacelab,

although the discoloration will be aesthetically undesirable. This occurrence should be a design consideration for the TOBE and SEXSAT thermal control systems. Degradation could be minimized by avoiding attitudes conducive to solar exposure of the payload bay area. Line-of-sight outgassing impacts from Spacelab surfaces to the TOBE and SEXSAT solar arrays, etc. needs further assessment, however, it could be significant. Consideration should be given to covering the TOBE and SEXSAT sensitive surfaces (optics and solar arrays) prior to activation, and deploying the SEXSAT early in the mission when degradation will be at a lower level. Activation of TOBE and SEXSAT high voltage systems should be delayed until high offgassing has ceased to prevent corona arc-over damage.

Firing of the SEXSAT solid deployment rockets in the vicinity of the Spacelab/Shuttle Orbiter will present a severe contamination potential to Spacelab and the TOBE. A deployment scheme must be devised to preclude any such rocket impingement and conversely any Shuttle Orbiter RCS impingement on the SEXSAT.

During both the launch and reentry phases a variety of contamination potentials will exist for those instruments mounted on the Spacelab tunnel platform, some of which may be quite severe. For this reason, protective covers should be utilized by the TOBE and SEXSAT during launch and by the TOBE during reentry and landing.

APPENDIX E

Major Shuttle Orbiter Sources Induced Environment Predictions

CONTENTS

1. INTRODUCTION

This Appendix presents in tabular form the current induced environment predictions for the major Shuttle Orbiter contaminant sources identified below.

Table E-I,	Materials Outgassing and Offgassing;
Table E-II,	Cabin Atmosphere Leakage;
Table E-III,	Evaporator Vents;
Table E-IV,	900 lb Reaction Control System Engines; and
Table E-V,	25 lb Vernier Control System Engines.

These are presented herein for completeness and for supplemental reference. The predictions in this Appendix reflect the most recent source, configuration, and methodology updates performed to date. Data presented is in the form of mass and number column densities and return flux at 700, 435, and 200 km altitudes for 9 basic Shuttle Orbiter lines-of-sight which are comparable to the Spacelab lines-of-sight contained in this report.

In addition, Figure E-1 presents schematically the modeled engine nodal numbers for reference in understanding the VCS 25 lb vernier and the RCS 900 lb engine data presented in the accompanying tables.

Table E-I. Outgassing/Offgassing Induced Environment Predictions For the Shuttle Orbiter Configuration

Predicted Parameters / Line-of-Sight/ Temperature	OUTGASSING Outgassing Rate** = 5×10^{-10} g/cm^2/second at 100°C					OFFGASSING Offgassing Rate = 2.5×10^{-9} g/cm^2/second at 100°C at 10 Hour Point				
	MCD	NCD	Return Flux (Max) (mol/cm^2/second)			MCD	NCD	Return Flux (Max) (mol/cm^2/second)		
	(g/cm^2)	(mol/cm^2)	700 km	435 km	200 km	(g/cm^2)	(mol/cm^2)	700 km	435 km	200 km
0° +Z										
Max	3.1(-11)*	2.0(+11)	3.3(+9)	9.0(+10)	Negli-gible	6.5(-11)	2.1(+12)	1.3(+9)	4.0(+10)	1.9(+12)
Min	1.4(-12)	8.8(+9)	1.5(+8)	4.0(+9)		3.0(-12)	9.9(+10)	5.9(+7)	1.7(+9)	8.9(+10)
50° ±Y										
Max	2.2(-11)	1.4(+11)	2.3(+9)	6.6(+10)		4.7(-11)	1.6(+12)	9.2(+8)	2.8(+10)	1.4(+12)
Min	1.4(-12)	8.8(+9)	1.5(+8)	4.0(+9)		2.9(-12)	9.6(+10)	5.6(+7)	1.7(+9)	8.6(+10)
25° ±Y										
Max	2.7(-11)	1.7(+11)	2.9(+9)	7.8(+10)		5.5(-11)	1.8(+12)	1.1(+9)	3.2(+10)	1.6(+12)
Min	1.4(-12)	8.8(+9)	1.5(+8)	4.0(+9)		3.0(-12)	9.9(+10)	5.9(+7)	1.7(+9)	8.9(+10)
50° ±Y 45° +X										
Max	2.8(-11)	1.7(+11)	3.0(+9)	7.8(+10)		6.0(-11)	2.0(+12)	1.2(+9)	3.3(+10)	1.8(+12)
Min	1.2(-12)	7.2(+9)	1.3(+8)	3.5(+9)		2.6(-12)	8.5(+10)	5.3(+7)	1.4(+9)	7.6(+10)
50° -X										
Max	2.4(-11)	1.5(+11)	2.6(+9)	7.2(+10)		5.0(-11)	1.7(+12)	1.0(+9)	3.0(+10)	1.5(+12)
Min	1.3(-12)	8.1(+9)	1.4(+8)	3.7(+9)		2.8(-12)	9.0(+10)	5.6(+7)	1.5(+9)	8.2(+10)
50° +X										
Max	3.8(-11)	2.4(+11)	4.0(+9)	1.1(+11)		8.0(-11)	2.7(+12)	1.6(+9)	4.6(+10)	2.3(+12)
Min	1.1(-12)	6.6(+9)	1.1(+8)	3.1(+9)		2.3(-12)	7.5(+10)	4.6(+7)	1.2(+9)	6.6(+10)

* $(-11) = 10^{-11}$

** Based on Shuttle Orbiter Reusable Surface Insulation Tile outgassing tests at NASA, MSFC.

Table E-II. Leakage Induced Environment Predictions for the Orbiter Configuration

Predicted Parameter / Line-of-Sight	MCD (g/cm^2)	NCD Total (mol/cm^2)	NCD O_2 (mol/cm^2)	NCD N_2 (mol/cm^2)	NCD CO_2 (mol/cm^2)	NCD H_2O (mol/cm^2)	Return Flux(Max) (mol/cm^2/second)		
							700 km	435 km	200 km
0° +Z	1.0(-9)*	2.2(+13)	4.6(+12)	1.7(+13)	1.5(+11)	3.9(+11)	1.3(+10)	3.7(+11)	2.0(+13)
50° ±Y	9.9(-10)	2.2(+13)	4.5(+12)	1.7(+13)	1.4(+11)	3.8(+11)	1.3(+10)	3.7(+11)	2.0(+13)
25° ±Y	1.1(-9)	2.4(+13)	5.1(+12)	1.9(+13)	1.6(+11)	4.3(+11)	1.4(+10)	4.1(+11)	2.1(+13)
50° ±Y 45° +X	8.8(-10)	1.9(+13)	4.0(+12)	1.5(+13)	1.3(+11)	3.4(+11)	1.1(+10)	3.2(+11)	1.7(+13)
50° -X	1.6(-9)	3.5(+13)	7.4(+12)	2.7(+13)	2.3(+11)	6.2(+11)	2.1(+10)	5.9(+11)	3.1(+13)
50° +X	8.6(-10)	1.9(+13)	4.0(+12)	1.5(+13)	1.2(+11)	3.3(+11)	1.1(+10)	3.2(+11)	1.7(+13)

* $(-9) = 10^{-9}$

Table E-III. Shuttle Orbiter Evaporator Induced Environment Predictions

Predicted Parameters / Line-of-Sight/Evaporators	MCD (g/cm^2) Direct Impingement	MCD (g/cm^2) Wing Reflection	MCD (g/cm^2) Total	NCD (mol/cm^2) Total	Return Flux (Max) ($mol/cm^2/second$) 700 km	Return Flux (Max) ($mol/cm^2/second$) 435 km	Return Flux (Max) ($mol/cm^2/second$) 200 km
0^o +Z							
+Y Evap.	0	2.6(-9)	2.6(-9)	8.7(+13)	5.3(+10)	1.4(+12)	7.9(+13)
-Y Evap.	0	2.6(-9)	2.6(-9)	8.7(+13)	5.3(+10)	1.4(+12)	7.9(+13)
Both	0	5.2(-9)	5.2(-9)	1.7(+14)	1.1(+11)	2.9(+12)	1.6(+14)
50^o +Y							
+Y Evap.	3.3(-9)*	6.3(-9)	9.6(-9)	3.3(+14)	1.9(+11)	5.3(+12)	2.8(+14)
-Y Evap.	0	2.6(-11)	2.6(-11)	8.5(+11)	5.3(+8)	1.4(+10)	7.6(+11)
Both	3.3(-9)	6.3(-9)	9.6(-9)	3.3(+14)	1.9(+11)	5.3(+12)	2.8(+14)
25^o +Y							
+Y Evap.	4.6(-10)	6.3(-9)	6.8(-9)	2.3(+14)	1.3(+11)	4.0(+12)	2.0(+14)
-Y Evap.	0	4.9(-10)	4.9(-10)	1.6(+13)	9.9(+9)	2.8(+11)	1.4(+13)
Both	4.6(-10)	6.8(-9)	7.4(-9)	2.4(+14)	1.4(+11)	4.3(+12)	2.1(+14)
50^o +Y, 45^o +X							
+Y Evap.	1.7(-9)	9.8(-9)	1.1(-8)	3.8(+14)	2.2(+11)	6.3(+12)	3.3(+14)
-Y Evap.	0	4.4(-12)	4.4(-12)	1.4(+11)	8.6(+7)	2.4(+9)	6.6(+9)
Both	1.7(-9)	9.8(-9)	1.1(-8)	3.8(+14)	2.2(+11)	6.3(+12)	3.3(+14)
50^o -X							
+Y Evap.	0	1.3(-9)	1.3(-9)	4.1(+13)	2.5(+10)	6.9(+11)	3.6(+13)
-Y Evap.	0	1.3(-9)	1.3(-9)	4.1(+13)	2.5(+10)	6.9(+11)	3.6(+13)
Both	0	2.6(-9)	2.6(-9)	8.2(+13)	5.0(+10)	1.4(+12)	7.3(+13)
50^o +X							
+Y Evap.	0	2.4(-9)	2.4(-9)	7.9(+13)	4.6(+10)	1.3(+12)	7.3(+13)
-Y Evap.	0	2.4(-9)	2.4(-9)	7.9(+13)	4.6(+10)	1.3(+12)	7.3(+13)
Both	0	4.8(-9)	4.8(-9)	1.6(+14)	9.2(+10)	2.7(+12)	1.4(+14)

* $(-9) = 10^{-9}$

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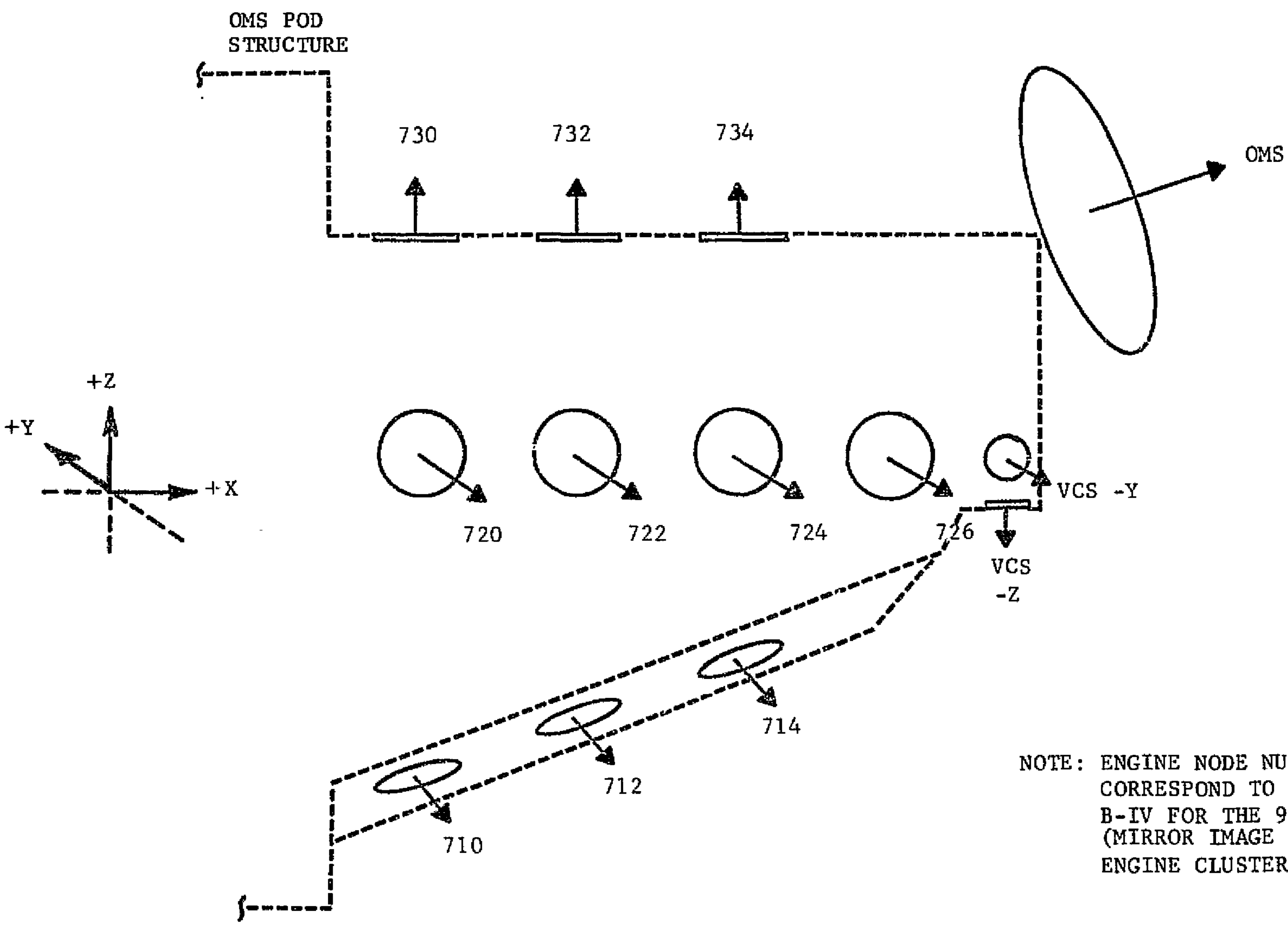
Table E-IV. 900 Lb Thrust Reaction Control System Engine Induced Environment Predictions

Predicted Parameters / LOS/ Engine (Direction)	MCD (g/cm^2) Total	NCD (mol/cm^2) Total	Return Flux (Max) ($mol/cm^2/second$) 700 km	435 km	200 km
*** **0° +Z**					
730(+Z)	3.3(-6)*	8.1(+16)	4.8(+13)	1.4(+15)	7.2(+16)
732	3.7(-6)	9.0(+16)	5.4(+13)	1.5(+15)	8.1(+16)
734	3.6(-6)	8.8(+16)	5.3(+13)	1.5(+15)	7.9(+16)
720 (-Y)	0.0	0.0	0.0	0.0	0.0
722	1.7(-8)	4.1(+14)	2.5(+11)	7.1(+12)	3.7(+14)
724	2.0(-8)	[illegible].9(+14)	2.9(+11)	8.3(+12)	4.4(+14)
726	2.1(-8)	5.1(+14)	3.1(+11)	8.7(+12)	4.6(+14)
710(**)	4.4(-12)	1.1(+11)	6.4(+7)	1.8(+9)	9.6(+10)
712	4.4(-12)	1.1(+11)	6.4(+7)	1.8(+9)	9.6(+10)
714	1.9(-10)	4.6(+12)	2.8(+9)	7.9(+10)	4.2(+12)
50° +Y					
730(+Z)	5.2(-7)	1.3(+16)	7.6(+12)	2.2(+14)	1.1(+16)
732	5.6(-7)	1.4(+16)	8.2(+12)	2.3(+14)	1.2(+16)
734	5.6(-7)	1.4(+16)	8.2(+12)	2.3(+14)	1.2(+16)
720(-Y)	9.7(-7)	2.4(+16)	1.4(+13)	4.0(+14)	2.1(+16)
722	9.5(-7)	2.3(+16)	1.4(+13)	3.9(+14)	2.1(+16)
724	9.3(-7)	2.3(+16)	1.4(+13)	3.9(+14)	2.1(+16)
726	9.1(-7)	2.2(+16)	1.3(+13)	3.8(+14)	2.0(+16)
710(**)	9.7(-11)	2.4(+12)	1.4(+9)	4.0(+10)	2.1(+12)
712	5.7(-9)	1.4(+14)	8.3(+10)	2.4(+12)	1.2(+14)
714	6.5(-9)	1.6(+14)	9.5(+10)	2.7(+12)	1.4(+14)
25° +Y					
730(+Z)	2.1(-7)	5.1(+15)	3.1(+12)	8.7(+13)	4.6(+15)
732	2.8(-6)	6.8(+16)	4.1(+13)	1.2(+15)	6.1(+16)
734	2.8(-6)	6.8(+16)	4.1(+13)	1.2(+15)	6.1(+16)
720(-Y)	1.1(-7)	2.7(+15)	1.6(+12)	4.6(+13)	2.4(+15)
722	1.1(-7)	2.7(+15)	1.6(+12)	4.6(+13)	2.4(+15)
724	1.1(-7)	2.7(+15)	1.6(+12)	4.6(+13)	2.4(+15)
726	1.1(-7)	2.7(+15)	1.6(+12)	4.6(+13)	2.4(+15)
710(**)	2.0(-11)	4.9(+11)	2.9(+8)	8.3(+9)	4.4(+11)
712	9.7(-10)	2.4(+13)	1.4(+10)	4.0(+11)	2.1(+13)
714	1.1(-9)	2.7(+13)	1.6(+10)	4.6(+11)	2.4(+13)
*** **50° +Y, 45° +X**					
730 (+Z)	3.3(-6)	8.1(+16)	4.8(+13)	1.4(+15)	7.2(+16)
732	3.3(-6)	8.1(+16)	4.8(+13)	1.4(+15)	7.2(+16)
734	3.2(-6)	7.8(+16)	4.7(+13)	1.3(+15)	7.0(+16)
720 (-Y)	5.8(-7)	1.4(+16)	8.5(+12)	2.4(+14)	1.3(+16)
722	5.9(-7)	1.4(+16)	8.6(+12)	2.4(+14)	1.3(+16)
724	6.0(-7)	1.5(+16)	8.8(+12)	2.5(+14)	1.3(+16)
726	6.0(-7)	1.5(+16)	8.8(+12)	2.5(+14)	1.3(+16)
710(**)	7.8(-9)	1.9(+14)	1.1(+11)	3.2(+12)	1.7(+14)
712	8.2(-9)	2.0(+14)	1.2(+11)	3.4(+12)	1.8(+14)
714	8.7(-9)	2.1(+14)	1.3(+11)	3.6(+12)	1.9(+14)
50° -X					
730(+Z)	0.0	0.0	0.0	0.0	0.0
732	5.4(-9)	1.3(+14)	7.9(+10)	2.2(+12)	1.2(+14)
734	1.1(-7)	2.7(+15)	1.6(+12)	4.6(+13)	2.4(+15)
720 (-Y)	0.0	0.0	0.0	0.0	0.0
722	0.0	0.0	0.0	0.0	0.0
724	0.0	0.0	0.0	0.0	0.0
726	0.0	0.0	0.0	0.0	0.0
710(**)	0.0	0.0	0.0	0.0	0.0
712	0.0	0.0	0.0	0.0	0.0
714	0.0	0.0	0.0	0.0	0.0
50° +X					
730(+Z)	4.6(-6)	1.1(+17)	6.7(+13)	1.9(+15)	1.0(+17)
732	5.2(-6)	1.3(+17)	7.6(+13)	2.2(+15)	1.1(+17)
734	5.4(-6)	1.3(+17)	7.9(+13)	2.2(+15)	1.2(+17)
720 (-Y)	3.3(-8)	8.1(+14)	4.8(+11)	1.4(+13)	7.2(+14)
722	3.3(-8)	8.1(+14)	4.8(+11)	1.4(+13)	7.2(+14)
724	1.2(-9)	2.9(+13)	1.8(+10)	5.0(+11)	2.6(+13)
726	3.5(-8)	8.5(+14)	5.1(+11)	1.5(+13)	7.7(+14)
710(**)	4.0(-10)	9.8(+12)	5.9(+9)	1.7(+11)	8.7(+12)
712	3.7(-10)	9.0(+12)	5.4(+9)	1.5(+11)	8.1(+12)
714	1.7(-10)	4.1(+12)	2.5(+9)	7.1(+10)	3.7(+12)

$*(-6) = 10^{-6}$

**Engine canted 20° about X & 12° about Y

*** See Figure E-1 for engine node configuration.



NOTE: ENGINE NODE NUMBERS PRESENTED CORRESPOND TO ENTRIES IN TABLE B-IV FOR THE 900 LB THRUST RCS (MIRROR IMAGE FOR +Y ORBITER ENGINE CLUSTER)

Figure E-1. Orbiter Aft Engine Cluster Geometric Relationships and Nodal Breakdown

Table E-V. Shuttle Orbiter VCS (25 Lb. Thrust) Induced Environment Predictions

PREDICTED PARAMETERS / LINE-OF-SIGHT & ENGINE FLUX DIRECTION	MCD (g/cm^2) DIRECT IMPINGMT.	MCD (g/cm^2) WING REFLECTION	MCD (g/cm^2) TOTAL	NCD (mol/cm^2) TOTAL	Return Flux(Max) ($mol/cm^2/second$) 700 km	Return Flux(Max) ($mol/cm^2/second$) 435 km	Return Flux(Max) ($mol/cm^2/second$) 200 km
0° + Z							
AFT -Z*	2.4(-10)***	1.8(-8)	1.8(-8)	4.4(+14)	2.7(+11)	7.6(+12)	3.9(+14)
AFT Y*	1.9(-9)	6.3(-9)	8.2(-9)	2.0(+14)	1.2(+11)	3.4(+12)	1.8(+14)
FWD Y/Z*	1.6(-10)	0	1.6(-10)	3.9(+12)	2.3(+9)	6.6(+10)	3.4(+12)
50° ± Y							
AFT -Z	7.3(-10)	3.3(-8)	3.4(-8)	8.3(+14)	4.9(+11)	1.4(+13)	7.3(+14)
AFT $-Z_{opp}$**	0	3.0(-10)	3.0(-10)	7.3(+12)	4.4(+9)	1.2(+11)	6.6(+12)
AFT Y	2.0(-8)	1.0(-8)	3.0(-8)	7.3(+14)	6.8(+11)	1.2(+13)	6.6(+14)
AFT Y_{opp}	0	2.9(-10)	2.9(-10)	7.1(+12)	4.1(+9)	1.2(+11)	6.3(+12)
FWD Y/Z	1.3(-9)	0	1.3(-9)	3.2(+13)	1.9(+10)	5.4(+11)	2.9(+13)
FWD Y/Z_{opp}	0	0	0	0	0	0	0
25° ± Y							
AFT -Z	3.4(-10)	3.4(-8)	3.4(-8)	8.3(+14)	4.9(+11)	1.4(+13)	7.3(+14)
AFT $-Z_{opp}$**	0	2.7(-9)	2.7(-9)	6.6(+13)	3.9(+10)	1.1(+12)	5.6(+13)
AFT Y	6.2(-9)	8.9(-9)	1.5(-8)	3.7(+14)	2.2(+11)	6.3(+12)	3.2(+14)
AFT Y_{opp}	0	3.5(-9)	3.5(-9)	8.5(+13)	5.1(+10)	1.5(+12)	7.6(+13)
FWD Y/Z	4.5(-10)	0	4.5(-10)	1.1(+13)	6.6(+9)	1.9(+11)	9.8(+12)
FWD Y/Z_{opp}	0	0	0	0	0	0	0
50° ± Y, 45° +X							
AFT -Z	5.4(-10)	5.8(-8)	5.9(-8)	1.4(+15)	8.5(+11)	2.4(+13)	1.3(+15)
AFT $-Z_{opp}$**	0	7.9(-11)	7.9(-11)	1.9(+12)	1.1(+9)	3.2(+10)	1.7(+12)
AFT Y	2.2(-8)	1.3(-8)	3.5(-8)	8.5(+14)	5.1(+11)	1.5(+13)	7.6(+14)
AFT Y_{opp}	0	6.3(-11)	6.3(-11)	1.5(+12)	9.3(+8)	2.7(+10)	1.4(+12)
FWD Y/Z	6.4(-10)	0	6.4(-10)	1.6(+13)	9.3(+9)	2.7(+11)	1.4(+13)
FWD Y/Z_{opp}	0	0	0	0	0	0	0
50° -X							
AFT -Z*	2.1(-11)	7.4(-9)	7.4(-9)	1.8(+14)	1.1(+11)	3.2(+12)	1.6(+14)
AFT Y*	2.9(-10)	3.0(-9)	3.3(-9)	8.1(+13)	4.9(+10)	1.4(+12)	7.3(+13)
FWD Y/Z*	1.1(-10)	0	1.1(-10)	2.7(+12)	1.6(+9)	4.6(+10)	2.4(+12)
50° +X							
AFT -Z*	1.4(-10)	3.2(-8)	3.2(-8)	7.8(+14)	4.6(+11)	1.3(+13)	7.1(+14)
AFT Y*	3.1(-9)	7.1(-9)	1.0(-8)	2.4(+14)	1.5(+11)	4.1(+12)	2.2(+14)
FWD Y/Z*	0	0	0	0	0	0	0

* Due to symmetry of this Line-of-Sight with respect to verniers, contributions to it from opposite side verniers are equal to values presented.

** Contribution to Line-of-Sight from vernier on opposite side of vehicle (Z_{opp}, Y_{opp}, Y/Z_{opp})

*** (-10) = 10^{-10}